JOURNAL
OF THE
American Society of Agronomy

VOL. 34 JULY, 1942 NO. 7

THE OCCURRENCE AND INHERITANCE OF CERTAIN LEAF "SPOTS" IN SUDAN GRASS[1]

R. J. GARBER AND S. J. P. CHILTON[2]

THE so-called "spotting" that frequently occurs on the leaves of sudan grass, *Sorghum vulgare* var. *Sudanense* (Piper) Hitchc., may be caused by bacterial or fungal organisms, by insect damage, or by mechanical injury. It is also possible that some "spotting" may be due to physiological conditions within the plant. Up to the present only negative results have been obtained in attempts to isolate a possible causal organism of the leaf spotting reported here.

Johnson[3] has briefly described three bacterial and three fungal diseases associated with foliar discolorations in sudan grass. The inheritance of plant colors in sorghum has been reviewed recently by Stephens and Quinby[4] and, therefore, no further review will be given here except to point out that the inheritance of such characters has been found to be simple. On the other hand, seed colors have been found to be somewhat more complex in their inheritance.

The purposes of the present paper are to describe leaf spots observed on selfed lines of sudan grass grown in the nursery at State College, Pa., during 1941, and to present data regarding the inheritance of three types of spotting.

OBSERVATION AMONG SELFED LINES IN 1941

In the nursery during 1941 a total of 464 selfed lines were grown in short rows with the plants individually spaced. The lines had been selfed from 2 to 4 years with the exception of a few that had been selfed for a longer period. The lines could be roughly divided into

[1]Contribution No. 32 of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the northeastern states. Received for publication February 28, 1942.

[2]Director and formerly Agent, respectively. The authors are indebted to Drs. K. W. Kreitlow and S. S. Atwood for help in taking some of the field notes, to the former for making some of the tests for possible causal organisms of the leaf spots, and to Dr. V. G. Sprague for the photographs.

[3]VINALL, H. N. Sudan grass. U. S. D. A. Farmers' Bul. 1126:20–22. 1920. (Revised 1940.)

[4]STEPHENS, J. C., and QUINBY, J. R. Linkage of the Q B Gs group in sorghum. Jour. Agr. Res., 57:747–757. 1938.

two classes, depending on whether they showed red[5] or tan spotting. Red spots occurred on 400 of the lines, tan on 59, and both red and tan spotted plants were found in each of the 5 remaining lines, which apparently were segregating. All but 5 of the 64 lines either breeding true for tan spotting or segregating could be definitely traced to plant material descendant from crosses between Leoti sorghum and sudan. There is the possibility that the five lines whose origin is somewhat obscure may have contained sorghum genes.

With respect to kind and degree of spotting, uniformity within lines but marked differences between them were observed. Types of spotting that occurred among the red lines are illustrated in Figs. 1 and 2.[6] Some lines were characterized by having large portions of their leaf midribs as well as spots on the blades colored red, and others rarely showed any red color on the midribs. Some lines produced large blotches more or less irregular in outline, while others showed only tiny spots. In some lines the spots seemed to coalesce particularly near the leaf tips. In a few lines the spots seemed to be distributed primarily along the leaf veins, resulting in parallel rows, whereas in other lines the spots occurred irregularly.

Variations in spotting also occurred among the tan lines but ap-

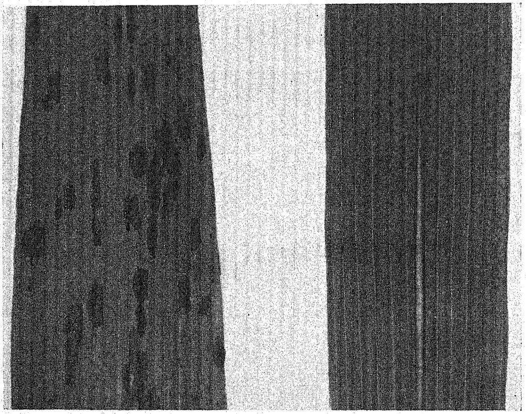


FIG. 1.—Typical leaves from two selfed "red" lines of sudan grass. At left, large blotches on blade red; at right, long section of midrib red.

[5]The intensity of color among the "red" lines varied from light to very dark. Some variation in intensity of color was also evident among the "tan" lines.

[6]All photographs for Figs. 1, 2, and 3 were taken the same day approximately 2 months after the lines were planted.

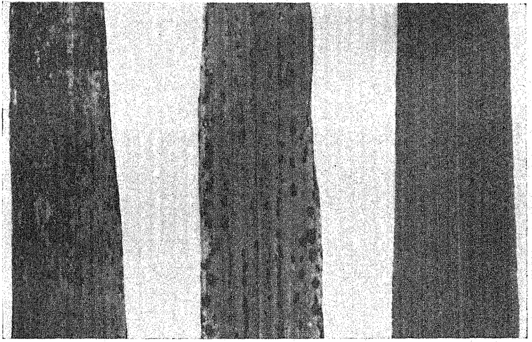


FIG. 2.—Typical leaves from three selfed "red" lines of sudan grass. From left to right, spots coalescing, spots in parallel rows, and tiny spots.

parently to a lesser degree. This seemingly less variation in spotting among the tan lines may have been an illusion due to the relatively inconspicuous color. No lines, either red or tan, were observed entirely free from spotting at the later stages of plant growth, although differences between lines in susceptibility to this condition were apparent.

In Fig. 3 are illustrated typical leaves of red and tan plants that occurred in each of two of the segregating selfed strains. Estimates of the number of spots on red and tan plants within these strains were obtained by making counts of the spots on 11 pairs of comparable leaves from red and tan plants. The tan leaves averaged 26 large frog-eye like spots per leaf, whereas the red leaves averaged 25. The difference is not significant. Counts of total number of spots readily discernible with the naked eye were made on this same material and similar results obtained. This evidence, although very meager, indicates that spotting is independent of the red pigment.

PARENTS USED IN CROSSES

As a result of observations both in the field and greenhouse, three lines of sudan grass which had been selfed for 3 years and which apparently were breeding true for "spotting" were chosen as parents. In 1940, the year the parents were chosen, the three lines 168, 186, and 152 began heading on August 18, 21, and 24, respectively.

Parent 152 was very susceptible, frequently showing numerous red spots on leaves of seedlings but 2 or 3 inches high. Leaf midribs were infrequently colored and when this did occur the red color was usually limited to a small section. As the plants became older it was

not uncommon for large areas of the leaves to be killed, apparently by the ravages of this disease.

Parent 186 was susceptible to tan spotting, particularly in the midribs, although many small spots also occurred on other parts of the leaves. The "spotting" in this strain developed somewhat later than in 152. The first conspicuous symptoms usually occurred when the plants were about a foot high and were manifest by a discoloring of large sections of the midribs occasionally affecting a midrib throughout its entire length. In the more severe cases the leaves were contracted transversally and died prematurely. In this strain a tan discoloration frequently occurred at the leaf collar and sometimes on the leaf sheath.

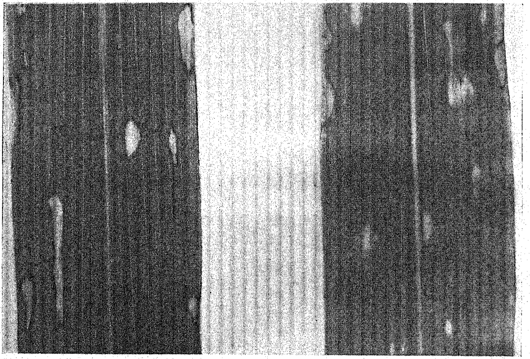


FIG. 3.—Typical leaves from red (at left) and from tan (at right) pigmented plants in the same selfed line of sudan grass.

Parent 168 apparently carried resistance to tan spotting during early plant growth. In fact, tan spots on this strain were usually not conspicuous until shortly before the plants headed. The spots at this time were neither as numerous nor as large as on the more susceptible 186 strain. Tan discolorations on the leaf midribs of 168 were infrequent and relatively small.

Typical leaves of the three parents when about midway in their normal growth period are shown in Fig. 4. It is obvious from the descriptions and the photograph that the parents differed in pigment coloring and in both time of appearance and manifestation of spotting. The difference between the parents in ability to produce red coloring was checked by pricking and scratching leaf surfaces with a dissecting needle. Strains 168 and 186 developed only tan pigment around the wounded tissue, whereas strain 152 developed red pigment.

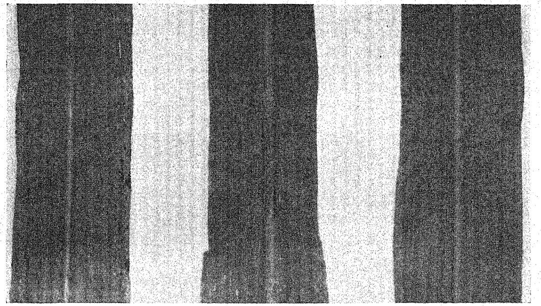


FIG. 4.—Typical leaves of the three sudan grass parents about midway in their life history. From left to right, 152 (red spotted), 186 (susceptible tan spotted), and 168 (resistant tan spotted). Note transversal constriction at affected midrib of parent 186.

METHOD OF GROWING AND DESCRIPTION OF THE HYBRIDS

The parents just described were crossed in all possible combinations and F_1 and F_2 generations along with the parents were grown in the greenhouse during the winter of 1940–41. The F_3 generations, some additional F_2 plants, and the parents were grown in the nursery during the summer of 1941. The greenhouse material was started in flats filled with a soil-sand mixture sterilized at low pressure. The plants from which the seed was desired were transferred to 6-inch pots and allowed to mature. The field material was grown in rod rows approximately a foot apart and the seeds spaced along the rows so as to enable one to distinguish individual plants. With few exceptions, 50 or more plants were available for study in each F_3 family. The reactions to spotting between the plants grown in the greenhouse and those grown in the field apparently were similar.

CROSS OF 152 WITH 168

The F_1 seedlings from the cross of the red spotted (152) sudan grass with the partially resistant tan spotted (168) one showed red spots on the leaves, but on the whole the spots were somewhat smaller and less numerous than on the red parent. The segregations with respect to color of leaf spots on the F_2 and F_3 generations are shown in Table 1. The data clearly indicate monohybrid inheritance with red color dominant.

Some variation was noted among the F_2 plants in time of appearance of red spots, but all plants capable of producing red color showed at least some red spotting by the time the plants were 5 weeks old. Considerable more variation was observed in degree of spotting both within the red group and the tan group, although somewhat more

conspicuous in the former due perhaps to the red color. The range of spotting regardless of color was in general between the parents and in relatively few instances did hybrid plants show the extremes manifest by the parents. Many of the red F_2 plants had less spotting than the red parent and a considerable number of the tan F_2 plants had more spotting than the tan parent. The nine F_3 red families, as well as the 11 F_3 tan families (Table 1), showed variation in amount of spotting between families as well as between plants in the same family.

TABLE 1.—*The segregation with respect to color of F_2 and F_3 generations from a cross between a susceptible red spotted (152) sudan and a partially resistant tan spotted (168) one.*

Culture	Generation	Number			Total	Expected recessives
		Red	Segregating	Tan		
		Grown in Greenhouse				
168×152	F_2 plants	482	—	162	644	161
152×168	F_2 plants	249	—	75	324	81
		Grown in Field				
168×152	F_2 plants	107	—	27	134	33.5
168×152	F_3 families	9	29	11	49	12.2

CROSS OF 152 WITH 186

The F_1 seedlings from the cross of red-spotted sudan (152) with the susceptible tan-spotted (186) one showed red spots on the leaves just as in the case of the F_1 from the cross of 152 with 168, but in the former case the spots appeared more abundant and larger. This seemingly greater susceptibility to spotting was also apparent in the F_2 and F_3 generations. The inheritance data with respect to color are shown in Table 2. Here again it is evident that the difference between red and tan is controlled by a single factor difference. Among

TABLE 2.—*The segregation with respect to color of F_2 and F_3 generations from a cross between susceptible red-spotted (152) and tan-spotted (186) sudan grass.*

Culture	Generation	Number			Total	Expected recessives
		Red	Segregating	Tan		
		Grown in Greenhouse				
152×186	F_2 plants	123	—	27	150	37.5
		Grown in Field				
152×186	F_3 families	43	74	26	143	35.7
152×186*	F_3 plants	559	—	189	748	187

*Sixteen F_3 families chosen at random and segregating for color.

the F_2 plants grown in the greenhouse, the deviation of the tan class from expectation is approximately two times its standard error. This deviation insofar as inheritance is concerned seems due to chance since in F_3 approximately one-third of the red-spotted F_2 plants bred true and two-thirds of them segregated. Sixteen F_3 families chosen at random and segregating for color produced 559 red and 189 tan plants, almost an exact monohybrid ratio.

It will be recalled that the tan-spotted parent (186) had relatively large sections of its leaf midribs colored tan, whereas the red-spotted parent (152) infrequently showed red discolorations on its leaf midribs. Eighty-three of the 123 red F_2 plants shown in Table 2 had red midribs. Chosen at random, 21 of the 43 F_3 families homozygous for red color were carefully examined for the presence of red midribs. Nine of these families each showed a few (1 to 5) plants with red midribs, eight showed somewhat more (7 to 14) plants with red midribs, one family produced only plants with red midribs, and three families showed no plants with red midribs. The classification of the F_2 phenotypes with respect to midrib discoloration used in this investigation did not prove to be a reliable index in forecasting the F_3 breeding behavior. The F_3 families segregating for red color showed similar variation with respect to coloring of the leaf midribs. The F_3 families homozygous for tan coloring also manifested variation in the expression of this character. Of 14 such families examined, 6 produced exclusively plants with sections of the leaf midribs discolored and the remaining 8 varied from one family with 2 out of 35 to another family with 55 out of 58 plants with tan midribs. The six F_3 families which produced exclusively plants with tan midribs varied in the extent of the leaf midrib section involved in the discoloration. As will be brought out more clearly in the next cross to be discussed, the degree of spotting recorded and even, to some extent, the relative number of spotted plants noted, regardless of coloring, depended upon the stage of maturity of the host plants. The final records for the cross under consideration here as well as those for the one discussed in the preceding section were made sometime after the plants were at least 8 weeks old and had reached the "boot" stage of development or had just begun to head.

CROSS OF 168 WITH 186

Inasmuch as the cross 168 with 186 did not involve red color, the inheritance data shown in Table 3 are free from any possible bias attributable to this source. It has already been pointed out that the partially resistant tan parent (168) did not show conspicuous spotting until about heading time, whereas the susceptible tan parent (186) usually began to show the characteristic discoloring of sections of the leaf midribs when the plants were about a foot high and were 4 to 5 weeks old. Most of the F_1 plants from this cross showed some tan discoloration near the leaf collar by the time the plants were 2 months old. When the F_2 plants, grown in the greenhouse, were about 8 weeks old, 19 plants had tan midribs, 53 showed tan coloring on and near the leaf collar, and 105 were without tan discolorations on the midrib

or collar, whereas 12 days later the respective classes obtained were 44, 44, and 89.

The hybrids grown in the field were planted on July 2 and 3. On September 9 the F_2 plants were classified according to extent (grades 1, 2, and 3) of midrib tanning. Seven plants were noted with midrib coloring (3) similar to that of the 186 parent, 38 with somewhat less midrib coloring (2), and 102 plants had only very small sections of the leaf midribs discolored (1) and in some cases these were very faint. No tan midribs were found on 12 of the 159 F_2 plants. When examined 12 days earlier, this same material showed 51 plants without any midrib discoloration. The F_3 families were likewise classified on two different dates. Eight of the 15 families which showed no plants with tan midribs on August 28 contained some plants with tan midribs by September 9. A great deal of variation with respect to extent of midrib discoloration was observed among the hybrids, but few of them approached the extreme susceptibility of one of the parents.

The F_2 classification with respect to spotting and the F_3 breeding behavior were not as closely correlated as one might expect. Using the records taken April 9 in the greenhouse and those taken September 9 in the field (Table 3), we find that the seven F_3 families without tan

TABLE 3.—*The segregation with respect to spotting of F_2 and F_3 generations from a cross between a susceptible tan-spotted (186) sudan grass and a partially resistant tan-spotted (168) one.*

<table>
<tr><th rowspan="2">Culture</th><th rowspan="2">Grown in</th><th rowspan="2">Generation</th><th rowspan="2">Observations made</th><th colspan="4">Number</th><th rowspan="2">Total</th></tr>
<tr><th>Tan midribs</th><th colspan="2">Tan collar</th><th>No color on midribs or collars</th></tr>
<tr><td>168×186</td><td>Greenhouse</td><td>F_2 plants</td><td>Mar. 28, 1941
Apr. 9, 1941</td><td>19
44</td><td colspan="2">53
44</td><td>105
89</td><td>177</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">No. and extent of midrib tanning</td><td>No color on midribs</td><td></td></tr>
<tr><td>168×186</td><td>Field</td><td>F_2 plants</td><td>Sept. 9, 1941</td><td>(3)
7</td><td>(2)
38</td><td>(1)*
102</td><td>12</td><td>159</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">Number of families</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>With tan midribs</td><td colspan="2">Segregating</td><td>Without tan midribs</td><td></td></tr>
<tr><td>168×186</td><td>Field</td><td>F_3 families</td><td>Aug. 28, 1941
Sept. 9, 1941</td><td>15
15</td><td colspan="2">55
63</td><td>15
7</td><td>85</td></tr>
</table>

*Grades of midrib tanning: 1, similar to the resistant parent; 2, intermediate; 3, similar to the susceptible parent.

midribs came from parental F_2 plants also without tan midribs, although one of them had a tan discoloration on the leaf collar. The 63 F_2 plants that produced the segregating F_3 progenies were classified as follows: 18 with some tanning on the leaf midribs, 9 with tan discolorations near the leaf collar, and 36 without discolorations on either of these plant parts. The 15 F_2 plants that produced exclusively progeny with tan midribs were classified as follows: 8 with tan midribs, 2 with tan discolorations on the leaf collars, and 5 without either of these discolorations. It should be borne in mind, however, that at these later stages of growth all plants had some spotting on the leaf blades.

The data obtained from the cross 168 with 186 are somewhat inconclusive, but they do indicate that both time and extent of the spotting described here are conditioned by a number of hereditary factors.

DISCUSSION

The cause of leaf spotting in sudan grass described in this paper has not been determined. Microscopical examinations have revealed cellular disintegration in diseased tissue. Whatever the cause, the affected leaf areas develop tan or red pigment, depending on the genotype for color. The pigments in themselves do not seem to be causative agents in producing the leaf spots; however, because of the fact that red is more conspicuous than tan, the red-pigmented lines are more conspicuously spotted than the tan-pigmented lines. The discoloration seems to be a consequence rather than a cause of spotting similar to what might follow any damage of the leaf by some disease organism, insect, or other agency.

Leaf spotting may cause considerable damage. In some selfed lines leaf spotting occurred very early in the life history of the plant, in others it did not occur until later; however, all lines showed more or less spotting by the time the plants had reached the heading stage. In the more susceptible lines leaf spotting seemed to be the most important factor in killing large leaf areas, particularly of the lower leaves of the plants. The more resistant lines showed less leaf damage but even in these considerable injury apparently attributable to spotting was observed by the time the plants had fully headed.

SUMMARY AND CONCLUSIONS

Of 464 lines of sudan grass selfed for 2 years or more and grown in the nursery in 1941, 400 carried red coloring, 59 tan, and the remaining 5 lines were apparently segregating for red and tan. All but five of the tan or segregating lines originated from plant material known to contain Leoti sorghum genes.

Data are presented that corroborate those of previous workers in showing that the inheritance of red and tan color is controlled by a single factor difference with red dominant.

No possible causal organisms were isolated in connection with the leaf spots under observation. In the red lines the spots were red or bordered with red and similarly in the tan lines the discolorations were tan.

The F_2 and F_3 data from crosses involving three types of leaf spotting as well as observations made among selfed lines of sudan grass indicate that the particular leaf spots under observation here are conditioned by inheritance but that the inheritance—disregarding color—is not simple. Leaf spots vary in size, shape, and number and in the time and place of appearance on the host plant.

THE SELENIUM CONTENT OF VEGETATION AND THE MAPPING OF SELENIFEROUS SOILS[1]

O. E. Olson, D. F. Jornlin, and A. L. Moxon [2]

IN June, 1939, the South Dakota Agricultural Experiment Station started grazing experiments with cattle on a ranch located in a seleniferous area of the state. To select the most desirable location for the experiment, both the opinions of the ranchers in that vicinity and the selenium analyses of soil and vegetation samples were considered. The ranch which was finally selected was reputed to be one of the most seleniferous in the area, and all ranchers who had operated it had experienced considerable trouble with selenium poisoning or "alkali disease" among their livestock.

It was necessary that as much information as possible be accumulated concerning the selenium content of the vegetation on this land in order to set up the pastures and to evaluate the results of the grazing studies; therefore, in 1938 studies were started on the selenium content of the vegetation. Secondary purposes of this study were (a) to determine the factors which influence the selenium content of plants and (b) to develop a practical method for mapping seleniferous land in sufficient detail to be of value on small ranches.

To date, most of the work which has been done in locating seleniferous soils has been of a reconnaissance nature. In addition to actual analysis of plants and soils, the occurrence of cases of selenium poisoning, of "indicator" plants, or of certain geological formations known to be seleniferous have been used in studying the occurrence of selenium. Whereas these means of locating seleniferous areas are of great value in reconnaissance work, their use in detailed mapping is quite limited.

Studies made earlier have shown that the analysis of plants is the most practicable and reliable means of determining, for the purpose of detailed mapping, the location of areas which are capable of producing vegetation of selenium content high enough to be toxic to livestock.[3] There are, however, several factors which cause variations in the selenium content of plants and these must be considered when plant analyses are used as an index of the amount of "available" selenium in soils. These factors have been discussed in an earlier publication and may be listed as follows: The amount of selenium in the soil; the chemical form of the selenium in the soil; the accumulation of selenium in the subsoil; the geological formation from which the soil was formed; the sulfur content of the soil; climatic conditions; the kind of plant; plant associations; the stage of growth of the plant; thrift and condition of the plant; the method of drying the plant for analysis; and the part of the plant analyzed. An effort has been made

[1]Contribution from the Chemistry Department, South Dakota Agricultural Experiment Station, Brookings, S. Dak. Approved for publication by the Director as contribution No. 157 of the Journal Series. Received for publication February 12, 1942.

[2]Analyst, Graduate Assistant, and Chemist, respectively.

[3]Unpublished data from this laboratory.

in this work to control all of these factors except those which were being studied further.

EXPERIMENTAL PROCEDURE

The first series of plant collections was begun in 1938 from 10 fenced plots, each 2 rods square, located at random over the four pastures. These collections were made for the purpose of studying the variation in the selenium content of plants as affected by several factors. At various times during the growing season several kinds of plants were cut just above the surface of the soil at random over all but the southwest one-fourth of each plot. These samples were then dried at 50° to 60° C for 48 hours since Beath, *et al.* (2),[4] report a negligible loss of selenium from grass samples when this method of drying is used. The plants were then ground in a Wiley mill and analyzed for selenium by the method described by Moxon (6).

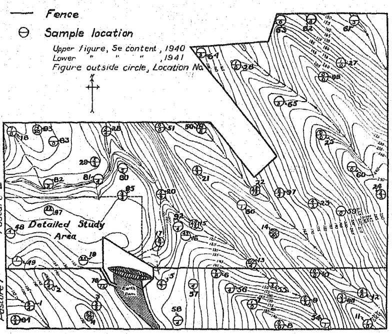


FIG. 1.—The selenium content of western wheat grass and its relation to contours on S. 2, T. 107N., R. 78W., S. Dak. (Topographic map prepared by Resettlement Administration, Land Utilization Division in 1937.)

The second series of plant collections was begun in 1940 for the purpose of establishing in some detail the location of highly seleniferous areas within the four past :res. On June 24 *Agropyron smithii* was sampled at random over circles 10 yards in diameter located at random over the four pastures. The samples were prepared for analysis and analyzed as described above. On July 11, 1941, *A. smithii* was again sampled at the same and at additional locations (Figs. 1 and 2),

[4]Figures in parenthesis refer to "Literature Cited", p. 615.

the size of the circles sampled being increased to a diameter of 30 yards, and analyzed as before.

RESULTS AND DISCUSSION

The results of the studies made to determine the selenium in *Agropyron smithii* growing on the four pastures are given in Figs. 1 and 2.

Agropyron smithii was selected as the plant to be collected from the several locations because it is one of the most important natural grasses in western South Dakota; it was found growing at most locations on the area studied; more data concerning its selenium content were available than for other grasses; and because it absorbs more selenium than other grasses of this area and therefore is advantageous in that it more clearly distinguishes between different amounts of "available" selenium in different soils.

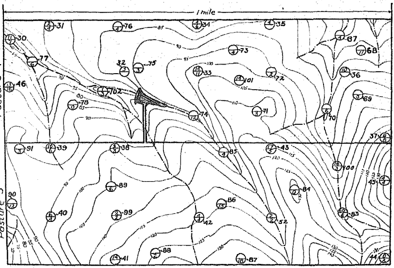


FIG. 2.—The selenium content of western wheat grass and its relation to contours on S. 35, T. 108N., R. 78W., S. Dak. (Topographic map prepared by Resettlement Administration, Land Utilization Division in 1937.)

In order that the selenium content of any species of plant can be successfully used as an index of available selenium in a soil and thereby be used in mapping "seleniferous" soils, the following must first be established: The variation in its selenium content during the growing season; the annual variation in its selenium content due to variations in climate; the relationship of selenium content of the "index" plant to that of other plants and the consistency of this relationship on different soils; the number of samples which must be collected over a given area; and the effects of topography and drainage on variations in the "available" selenium content of the soil. These factors will be discussed in considering the data accumulated from the two series of plant collections described earlier in this paper.

EFFECT OF STAGE OF GROWTH OF PLANTS ON THEIR SELENIUM CONTENT

Plant collections have been made from the square fenced plots since 1938. The kinds of plants analyzed have depended largely on the kinds present in the various plots. The results of some of these analyses are listed in Tables 1, 2, 3, and 4. The results on *Agropyron smithii* as given in Table 1 agree with those found in former studies (7). Generally, in young plants, there is a high selenium content which decreases slowly until after the plant has reached maturity, when the decrease is quite marked. This rapid decrease in selenium content after maturity is probably the result of the combined effect of leaching, loss of selenium in volatile form, and the shedding of seeds in which the selenium content is probably fairly high. These results indicate that variations in the selenium content of the grass are small during June and the first week of July, and it appears that under normal conditions of climate these variations may be considered as negligible as compared to sampling error. The results on *Stipa viridula* are very similar to those for *A. smithii*, and similar results have likewise been obtained on *S. comata*, *Bouteloua gracilis*, and *B. curtipendula* (7). *Helianthus* sp. shows a relatively stable selenium content during its early stages and through maturity, but upon drying a rapid loss of selenium occurs. The same factors suggested for the rapid loss of selenium in *A. smithii* following maturity may be responsible for the loss in the case of *Helianthus*. Results on several other weeds indicate that the same conditions hold for them as are true of *Helianthus*.

TABLE 1.—*The selenium content of western wheat grass Agropyron smithii Rydb., at different stages of its growth.*

Date of collection	Stage of growth	Selenium content in p.p.m. oven-dry basis				
		Plot 1	Plot 5	Plot 8	Plot 9	Plot 10
		1939				
June 12....	Pre-heading	28	6	11	11	7
June 22....	Early heading	23	7	10	8	7
July 6.....	Heading	18	6	7	9	6
July 22.....	Maturing	14	10	7	5	7
Aug. 16....	Late maturity	12	3	5	5	4
Sept. 19....	Dry	3	T*	6	6	3
		1940				
May 27....	Pre-heading	26	9	11	13	6
June 10....	Pre-heading	32	8	14	12	5
June 24....	Early heading	33	8	16	14	7
July 11.....	Maturing	23	4	8	1	–†
Aug. 29....	Dry	9	5	5	–†	3
		1941				
May 17....	Pre-heading	20	8	20	10	4
June 20....	Pre-heading	20	4	6	9	6
July 11.....	Headed, early maturity	20	4	3	8	3
Sept. 10....	Drying	17	6	7	9	2

*Trace.
†No sample collected.

TABLE 2.—*The selenium content of feather grass, Stipa viridula Trin., at different stages in its growth.*

Date of collection	Stage of growth	Selenium content in p.p.m. oven-dry basis			
		Plot 1	Plot 8	Plot 9	Plot 10
		1939			
June 12	Headed	15	9	10	5
June 22	Early maturity	22	6	11	4
July 6	Seed shedding	16	7	11	4
July 22	Mature	18	6	6	—†
Aug. 16	Drying	12	4	5	T*
Sept. 19	Dry	7	4	T*	—†
		1940			
May 27	Pre-heading	24	—†	14	—
June 10	Headed	17	6	11	—
June 24	Seed shedding	14	8	5	—
July 11	Drying	13	1	1	—
Aug. 29	Dry	5	1	4	—

*Trace.
†No sample taken.

TABLE 3.—*The selenium content of sunflowers, Helianthus sp., at different stages in their growth.*

Date of collection	Stage of growth	Selenium content in p.p.m. oven-dry basis				
		Plot 1	Plot 5	Plot 8	Plot 9	Plot 10
		1938				
May 23	Early (2 in. tall)	—*	14	—	—	—
June 27	Blossom	40	4	—	—	—
Aug. 4	Mature	48	3	—	—	—
Oct. 2	Dry	10	—*	—	—	—
		1939				
June 12	Bud	58	12	15	30	15
June 22	Blossom	46	13	10	—*	13
July 6	Blossom	47	12	12	37	7
July 22	Drying	38	5	11	—*	7
Aug. 16	Dry	14	4	7	10	3
Sept. 19	Dry	2	T†	4	—*	4

†Trace.
*No sample taken.

Grindelia squarrosa, unlike most of the other plants examined, has been found to increase steadily until even late stages in its growth when its selenium content is high, but the opposite trend apparently occurs when its selenium content is low. Interesting speculations might be made concerning reasons for the variability in accumulating selenium, as is indicated by the data, but thus far no experimental work has been done to explain it. There is evidence (7) that other plants may act much like *Grindelia* in this respect.

TABLE 4.—*The selenium content of gum plant, Grindelia squarrosa (Pursh) Dunal., at different stages of its growth.*

Date of collection	Stage of growth	Selenium content in p.p.m. oven-dry basis			
		Plot 1	Plot 3	Plot 8	Plot 10
		1938			
June 27	Pre-blossom	—	—	—	160
Aug. 4	Blossom	—	—	—	230
Oct. 2	Mature	—	—	—	230
		1939			
June 12	Pre-bud	133	33	20	120
June 22	Early bud	267	32	—*	160
July 6	Bud	292	30	267	280
July 22	Early blossom	430	16	—*	450
Aug. 16	Blossom	620	8	300	244
		1940			
June 10	Pre-bud	—	—	280	—
June 24	Pre-bud	—	—	910	—
July 11	Drying	—	—	750	—

*No sample taken.

In view of the work done in respect to the selenium content of plants at various stages of growth, it seems probable that those plants which are the most palatable to range animals have a high selenium content in the spring and summer seasons as compared to their selenium content in the fall, and that the decrease in selenium content is not rapid until after maturity.

VARIATION BETWEEN SELENIUM CONTENT OF DIFFERENT KINDS OF PLANTS

It has been demonstrated that certain plants such as *Astragalus racemosus* and *Stanleya bipinnata*, "converter" plants are capable of accumulating large concentrations of selenium (1, 3). Moxon, *et al.*, (7) have presented data showing that in plants not considered highly seleniferous there is a variation in their selenium content which apparently is due only to differences in the plants themselves. They have also presented data on the comparative selenium content of various grasses.

During the past four years several samples of *Agropyron smithii* have been collected from definite locations on the land used in these studies. In many instances samples of *Stipa viridula* have been taken at the same time. The selenium content of these samples has been used in computing the data for Table 5.

The data in Table 5 are in agreement with those in an earlier publication (7) *Agropyron smithii*, it appears, is the more seleniferous of the two grasses, containing an average of one and one-half times as much selenium as *Stipa viridula* when growing under the same conditions. This relationship holds on soils of either high or low "available" selenium content.

TABLE 5.—*A comparison between the selenium content of Agropyron smithii Rydb. and Stipa viridula Trin.*

Grass	No. of samples	Av. Se content, p.p.m.	Ratio of Se in *S. viridula* to Se in *A. smithii*	No. of samples Se in *S. viridula* more than Se in *A. smithii*	No. of samples Se in *S. viridula* equal to Se in *A. smithii*	Range of Se in *A. smithii*, p.p.m.
			Comparison I			
A. smithii *S. viridula*	12 12	35.7 23.6	1:1.51	1	0	20 and over
			Comparison II			
A. smithii *S. viridula*	20 20	13.5 8.4	1:1.61	1	1	10–19 inclusive
			Comparison III			
A. smithii *S. viridula*	40 40	6.1 4.2	1:1.45	4	6	3–9 inclusive
			Totals			
A. smithii *S. viridula*	72 72	13.1 8.6	1:1.52	6	7	——

Other data on the comparative selenium content of other grasses are on hand and are in agreement with those already published (7).

Since it seems that the most accurate method of determining the availability to plants of selenium in soils is the analysis of plants growing in the soils, it is of interest to know whether or not the results for one species will be accurate when applied to another species. The data in Table 6 indicate that results for *Agropyron smithii* may well be applied to other plants, if the differences in the abilities of the two plants to absorb selenium are considered.

ANNUAL VARIATION IN SELENIUM CONTENT OF *Agropyron smithii*

Conflicting views have been advanced concerning the effect of climate (rainfall) on selenium absorption by plants (4, 5). However, it is apparent that the possibility of such an effect occurs and therefore must be considered in this study.

An examination of the results as given in Fig. 1 indicates that generally the selenium content of the *Agropyron smithii* collected during 1940 was for all practical purposes the same as that for 1941, in spite of the fact that a difference existed in the size of plots sampled. However, the amount of rainfall during these two seasons was approximately the same and therefore no conclusions can be drawn as concerns variation in selenium content of plants with rainfall except that only when the amount of rainfall varies to a large degree from the normal can any significant differences be expected when methods such as were used here are employed. It cannot be said that in no cases were any significant differences found between the selenium content of the 1940 and 1941 samples because in several cases large

TABLE 4.—*The selenium content of gum plant, Grindelia squarrosa (Pursh) Dunal., at different stages of its growth.*

Date of collection	Stage of growth	Selenium content in p.p.m. oven-dry basis			
		Plot 1	Plot 3	Plot 8	Plot 10
		1938			
June 27	Pre-blossom	—	—	—	160
Aug. 4	Blossom	—	—	—	230
Oct. 2	Mature	—	—	—	230
		1939			
June 12	Pre-bud	133	33	20	120
June 22	Early bud	267	32	—*	160
July 6	Bud	292	30	267	280
July 22	Early blossom	430	16	—*	450
Aug. 16	Blossom	620	8	300	244
		1940			
June 10	Pre-bud	—	—	280	—
June 24	Pre-bud	—	—	910	—
July 11	Drying	—	—	750	—

*No sample taken.

In view of the work done in respect to the selenium content of plants at various stages of growth, it seems probable that those plants which are the most palatable to range animals have a high selenium content in the spring and summer seasons as compared to their selenium content in the fall, and that the decrease in selenium content is not rapid until after maturity.

VARIATION BETWEEN SELENIUM CONTENT OF DIFFERENT KINDS OF PLANTS

It has been demonstrated that certain plants such as *Astragalus racemosus* and *Stanleya bipinnata*, "converter" plants are capable of accumulating large concentrations of selenium (1, 3). Moxon, *et al.*, (7) have presented data showing that in plants not considered highly seleniferous there is a variation in their selenium content which apparently is due only to differences in the plants themselves. They have also presented data on the comparative selenium content of various grasses.

During the past four years several samples of *Agropyron smithii* have been collected from definite locations on the land used in these studies. In many instances samples of *Stipa viridula* have been taken at the same time. The selenium content of these samples has been used in computing the data for Table 5.

The data in Table 5 are in agreement with those in an earlier publication (7) *Agropyron smithii*, it appears, is the more seleniferous of the two grasses, containing an average of one and one-half times as much selenium as *Stipa viridula* when growing under the same conditions. This relationship holds on soils of either high or low "available" selenium content.

TABLE 5.—*A comparison between the selenium content of Agropyron smithii Rydb. and Stipa viridula Trin.*

Grass	No. of samples	Av. Se content, p.p.m.	Ratio of Se in *S. viridula* to Se in *A. smithii*	No. of samples Se in *S. viridula* more than Se in *A. smithii*	No. of samples Se in *S. viridula* equal to Se in *A. smithii*	Range of Se in *A. smithii*, p.p.m.
			Comparison I			
A. smithii *S. viridula*	12 12	35.7 23.6	1:1.51	1	0	20 and over
			Comparison II			
A. smithii *S. viridula*	20 20	13.5 8.4	1:1.61	1	1	10–19 inclusive
			Comparison III			
A. smithii *S. viridula*	40 40	6.1 4.2	1:1.45	4	6	3–9 inclusive
			Totals			
A. smithii *S. viridula*	72 72	13.1 8.6	1:1.52	6	7	——

Other data on the comparative selenium content of other grasses are on hand and are in agreement with those already published (7).

Since it seems that the most accurate method of determining the availability to plants of selenium in soils is the analysis of plants growing in the soils, it is of interest to know whether or not the results for one species will be accurate when applied to another species. The data in Table 6 indicate that results for *Agropyron smithii* may well be applied to other plants, if the differences in the abilities of the two plants to absorb selenium are considered.

ANNUAL VARIATION IN SELENIUM CONTENT OF *Agropyron smithii*

Conflicting views have been advanced concerning the effect of climate (rainfall) on selenium absorption by plants (4, 5). However, it is apparent that the possibility of such an effect occurs and therefore must be considered in this study.

An examination of the results as given in Fig. 1 indicates that generally the selenium content of the *Agropyron smithii* collected during 1940 was for all practical purposes the same as that for 1941, in spite of the fact that a difference existed in the size of plots sampled. However, the amount of rainfall during these two seasons was approximately the same and therefore no conclusions can be drawn as concerns variation in selenium content of plants with rainfall except that only when the amount of rainfall varies to a large degree from the normal can any significant differences be expected when methods such as were used here are employed. It cannot be said that in no cases were any significant differences found between the selenium content of the 1940 and 1941 samples because in several cases large

differences occurred. However, it is to be noted that these cases where large differences occurred were in draws where it might be expected that the amount of soluble selenium in the soil will vary according to its alternate deposition and leaching by runoff waters. This phase of the problem needs more study.

TABLE 6.—*The absorption of selenium from different soils by A. smithii, S. viridula, and Helianthus sp.*

Species of plant	Selenium content in p.p.m. of plants from plots indicated							
	1	2	3	5	7	8	9	10
Sampled June 12, 1939								
A. smithii	28	2	3	6	—*	11	11	8
S. viridula	15	2	—*	—*	2	9	10	5
Helianthus sp	58	—*	3	12	6	15	30	15
Sampled June 22, 1939								
A. smithii	23	1	6	7	2	10	11	7
S. viridula	22	1	—*	—*	—*	6	8	4
Helianthus sp	46	—*	3	13	5	10	—*	13
Sampled July 6, 1939								
A. smithii	18	0	5	6	4	7	9	6
S. viridula	16	0	—*	—*	4	7	11	4
Helianthus sp	47	—*	4	12	5	12	37	7
Sampled June 10, 1940								
A. smithii	32	T†	5	8	1	14	12	5
S. viridula	17	T†	—*	—*	1	6	11	6
Helianthus sp	50	—*	6	9	—*	22	—*	—*
Sampled June 24, 1940								
A. smithii	33	2	—*	8	2	16	15	7
S. viridula	14	1	—*	—*	2	8	5	3
Helianthus sp	70	—*	—*	2	—*	24	—*	—*
Average								
A. smithii	27	1	4	7	2	12	17	7
S. viridula	17	1	—*	—*	2	7	9	4
Helianthus sp	54	—*	3	10	5	17	34	12

*No sample taken.
†Trace.

VARIATION IN SELENIUM CONTENT OF *Agropyron smithii* AS RELATED TO TOPOGRAPHY

Byers (3) analyzed plants and soil samples from a section of seleniferous land in an effort to determine whether or not any relationship existed betweem their selenium content and topography. He concluded that no relationship existed. The data presented in Fig. 1 apparently support his conclusions. There is no strict relationship between available selenium in soils and topography. However, insofar as topography is an aid in mapping geological formations it is of

value in locating seleniferous areas, since it has been demonstrated that the occurrence of selenium is definitely correlated with certain geological strata (7).

The data in Figs. 1 and 2 illustrate in several instances a correlation between the selenium content of the grass and topography. For instance, several samples at elevation 115 feet are relatively high in selenium content. This in turn can be correlated with the occurrence of a chalky zone of relatively high selenium content at approximately this level. At all elevations above 180 feet the selenium content of the vegetation is relatively low, and several samples of shale from a fresh road cut at these elevations have been found to be of low selenium content. Thus, a general division can be made between the "seleniferous" and "nonseleniferous" portions of these pastures on the basis of topography. Variations in the amount of windblown material, wash, erosion, leaching, weathering, and deposition of soluble selenium, as well as variations in the selenium content of the soils below 180 feet elevation, cause variations in the amount of "available" selenium present in the soils mapped as generally seleniferous and makes the use of topography for greater detail uncertain.

SUMMARY

The selenium content of *Agropyron smithii* and some other plants has been found to remain fairly constant during the stages of growth up to maturity, following which it decreases rapidly.

The selenium content of *Agropyron smithii* appears to be a relative index to the amount of selenium in soils which is available to common range plants.

A convenient method for differentiating between areas of high and low "available" selenium in soils has been devised. This method, it appears, will prove practicable only where detailed work is essential, geological studies being better suited for work of a reconnaissance nature.

LITERATURE CITED

1. BEATH, O. A., EPPSON, H. F., and GILBERT, C. S. Selenium and other toxic minerals in soils and vegetation. Wyo. Agr. Exp. Sta. Bul. 206. 1935.
2. ———, ———, ———. Selenium distribution in and seasonable variation of type vegetation occurring on seleniferous soils. Jour. Amer. Pharm. Assoc., 26:394–405. 1937.
3. BYERS, H. G. Selenium occurrence in certain soils in the United States with a discussion of related topics. U. S. D. A. Tech Bul. 482. 1935.
4. ———. Selenium occurrence in certain soils in the United States with a discussion of related topics. 2nd Rpt. U. S. D. A. Tech. Bul. 530. 1936.
5. FRANKE K. W., and PAINTER, E. P. The effect of sulphur additions on seleniferous soils and binding of selenium by soils. Ind. and Eng. Chem., 29:591–595. 1937.
6. MOXON, A. L. Alkali disease or selenium poisoning. S. Dak. Agr. Exp. Sta. Bul. 311. 1937.
7. ———, OLSON, O. E., and SEARIGHT, W. V. Selenium in rocks, soils and plants. S. Dak. Agr. Exp. Sta. Tech. Bul. 2, 1939.

A BIOLOGICAL REDUCTION METHOD FOR REMOVING FREE IRON OXIDES FROM SOILS AND COLLOIDAL CLAYS[1]

L. E. Allison and G. D. Scarseth[2]

THE interfering effect of free iron oxides, abundantly present in the colloidal fraction of most weathered soils, has long been recognized, especially in studies involving mechanical analysis, mineralogical analysis, whether by X-ray or petrographic means, specific gravity separations, and phosphate fixation. Because of their abundance in both the hydrated and unhydrated forms, they frequently mask the surfaces of soil particles, imparting to them many of the properties of the oxides themselves, especially color.

A special method for removing free iron oxides from soils and soil colloids was devised by Drosdoff and Truog (4).[3] It involves the saturation of a soil or colloid suspension with hydrogen sulfide until all the free iron oxides are reduced, addition of NH_4OH to render slightly alkaline, followed by acidification with dilute HCl to dissolve the black iron sulfides formed. Final removal of the dissolved iron is accomplished by repeated washing in dilute HCl by means of the centrifuge. More recently, Truog and his associates (13) suggested the use of a sodium sulfide-oxalic acid treatment which releases nascent H_2S and more effectively reduces free iron oxides than the method of Drosdoff and Truog. In addition, it removes any free alumina and silica present and may also attack some of the iron in iron base exchange material such as nontronite. This method is especially recommended by its authors for special cases of mechanical and mineralogical analysis of soils.

Metzger (9) and Chandler (3) used this method to prepare their samples for studies on phosphate fixation. However, Toth (12) has indicated a preference for the Drosdoff-Truog procedure for similar studies because of its less drastic action "resulting in a less intense degradation of the complex."

In contrast to the two chemical methods for removing free iron oxides from soils and clays, the writers have devised a biological method employing the principle of microbial reduction. Simply stated, it involves the addition of a readily available source of energy material, such as sucrose, to a soil or colloid suspension and incubating under an anaerobic environment. No inoculum appears to be necessary, although this point is being investigated. When the dissolved iron is removed, a gray (reduced) glei-colored soil or colloid results.

The role of microorganisms in dissolving iron compounds in nature has long been known. In 1836, Kindler (7) noted the solution of iron around roots of plants growing in ferruginous sands. Winogradsky (14) used anaerobic conditions to promote solution of ferric iron

[1]Joint contribution from the School of Agriculture and the Agricultural Experiment Station, Purdue University, Lafayette, Indiana. Journal paper No. 3 of the Agricultural Experiment Station. Received for publication February 26, 1942.

[2]Assistant Professor of Soils, School of Agriculture, and Soil Chemist, Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 623.

as a source of this element for his "iron" bacteria. More recently, Lieske (8) observed the reducing effect of molds on ferric compounds. He also observed that sucrose has a solvent effect on hydrated iron oxides. Wright (15) studied the effect of dextrose fermentation on mineral solubility, and concluded that the observed solution effect was the result of an increased hydrogen-ion concentration.

The effect of peat solutions on finely ground (200 mesh) minerals and rocks was studied by Gruner (5), who found that such organic materials dissolved oxides and carbonates of iron and most silicates, but that the solvent action was slowest on those minerals containing ferric forms of iron. This slower action may be attributed to the time necessary first to reduce ferric iron to the ferrous form before it became soluble. In all of his work iron was dissolved more rapidly in the absence rather than in the presence of air.

Starkey and Halverson (11) point out that microorganisms may alter two conditions which have a controlling influence upon iron transformations, namely, (a) the reaction of the medium, and (b) the oxygen pressure of tension. Under anaerobic conditions, they create a very low oxygen tension which in itself controls the ratio of reduced iron (Fe^{++}) to oxidized iron (Fe^{+++}) in the direction of the reduced state. In the presence of fermenting carbohydrates, organic acids are produced, often in sufficient quantity to attain a pH of 3.0 in an unbuffered medium. Undoubtedly these acids exert an appreciable solvent action on iron-bearing compounds. Thus, it is apparent that microorganisms under the proper environment may exert a strong reducing and solvent action on iron compounds, especially in soil and colloidal suspensions which present a large surface area.

BIOLOGICAL REDUCTION PROCEDURE FOR REMOVING FREE IRON OXIDES

SOIL MATERIAL

Place 10 to 50 grams of soil or subsoil in a 250-ml Erlenmeyer flask, add sucrose equal to 5% of the weight of soil, mix well, and then cover with distilled water to a depth of 2 inches. Close flask with a one-hole stopper containing a bent glass tube extending into a small vial of water, thus providing an air seal to exclude oxygen. Incubate at not above 25° C until reduction is complete, as evidenced by gray color of soil. If reduction is incomplete after all sugar is fermented, then more energy material may be added and the process continued. If the quantity of iron oxides to be removed is large, it may be necessary to siphon off the clear supernatant liquid rich in ferrous iron, add more sugar, and repeat the fermentation process.

Final removal of soluble iron from the reduced soil is affected as described subsequently for soil colloids.

SOIL COLLOIDS

Colloidal clays reduce more rapidly when completely dispersed in about a 2 or 3% suspension. As much as 100 grams of colloid may be conveniently reduced, when fermented with sucrose equal to 5% of the colloid present, in about 5 or 6 liters volume in a 2-gallon bottle provided with a water seal as described for soils. A more satisfactory anaerobic environment may be secured by displacing the air

from the bottle above the suspension with carbon dioxide, although this step is not necessary to initiate the fermentation.

Shortly after fermentation begins, usually within 5 to 12 days, the colloid turns bluish-gray, flocculates, and settles out. It should be allowed to stand 3 or 4 days longer for the supernatant liquid to become clear, after which it is siphoned off. If the reduction appears incomplete, further fermentation is necessary. In this case it is best to remove completely the clear supernatant liquid, which frequently contains more than half of the soluble iron, by displacing it with a stream of CO_2 under pressure so as to exclude oxygen from the bottle. The original volume is restored by adding water containing sugar equal to from 3 to 5% of the weight of the colloid and the fermentation continued again as before. When reduction of the clay is completed, the supernatant liquid is again siphoned off and combined with that previously removed.

The soluble iron remaining in the flocculated colloid (or soil) is washed out by centrifuging four times with a 5% NaCl solution acidified to pH 3.00 with HCl, or until 5 cc of the washings show no evidence of iron on addition of one drop of H_2O_2 and 1 ml of dilute alcoholic KCNS solution. Thereafter wash with distilled water until free NaCl is removed.

The iron oxide-free colloid is further treated in a large beaker to remove microbial tissue and other organic materials by adding 50 ml of 30% H_2O_2 and evaporating down to a thick paste at 50° to 60° C. Placing the beaker on top of an oven operating at 110° C is satisfactory for evaporation.

If iron is to be determined, the siphonates and salt washings are combined and treated with a few ml of 10% H_2O_2 to oxidize all ferrous iron to the ferric form. The total volume is taken to dryness with HNO_3 and the process repeated as necessary to oxidize all organic matter, followed by a final evaporation with a few ml of HCl to remove excess HNO_3. The residue is taken up in HCl and the iron determined in an aliquot by standard methods.

RESULTS

COMPARISON OF BIOLOGICAL METHOD AND CHEMICAL METHOD OF TRUOG FOR REMOVAL OF FREE IRON OXIDES AS MEASURED BY IRON REMOVAL

A colloidal clay fraction (particle diameter $<1\ \mu$) separated from the B horizon of a Miami silt loam was used to afford a comparison between the two methods. Twenty grams of this colloid were reduced by the chemical method of Truog, *et al.* (13), and 100 grams were biologically reduced by fermenting with 7% of sucrose in a suspension volume of 6 liters during an 18-day incubation period.

An analysis of the extracts for iron oxide, alumina, and silica was carried out by standard methods and the data reported in Table 1. It is apparent that the two methods give good agreement in regard to removal of free iron oxides with a slight advantage in favor of the biological reduction process. However, this method does not remove more than traces of alumina and silica as compared to appreciable removals by the chemical method.

TABLE 1.—*Removal of free iron oxides, alumina, and silica from Miami colloid by chemical and biological methods.*

Constituent determined	Total quantity in 100 grams of colloid, grams	Constituents removed per 100 grams of colloid			
		Biological method		Chemical method*	
		Grams	%	Grams	%
Iron oxide........	10.51	2.5060	23.85	2.3065	21.94
Alumina.........	21.58	0.2838	0.13	1.1500	5.33
Silica............	52.10	0.1516	0.29	1.0360	1.98

*A 20-gram sample was used, but analyses are expressed on the 100-gram basis.

COMPARISON OF BIOLOGICAL AND CHEMICAL METHODS FOR REMOVING FREE IRON OXIDES AS MEASURED BY PHOSPHATE FIXATION

Since several studies of phosphate fixation (3, 9, 12) have recently been made in which colloids or soils were chemically treated to remove interfering iron oxides, it was considered advisable to compare the biological method for this purpose with the chemical method of Truog (13). For this purpose portions of the Miami colloid, reduced by the two methods, along with the untreated colloid were electrodialyzed and used as samples. The quantity of iron removed by each treatment is shown in Table 1. Adsorption experiments were set up according to the technic described by Scarseth (10), using NaOH to adjust the reaction and with minor variations as follows: One gram of clay was used per flask in a total volume of 100 ml; phosphate was added as H_3PO_4 at two different rates, *viz.*, 5 and 30 millimols per 100 grams of clay, and the equilibrium period was 5 days during which flasks were agitated three times daily. Phosphate determinations were made by the method of Benedict and Theis (1).

The data obtained from these experiments cover a wide range of pH values and are expressed in the form of curves shown in Fig. 1. Curve A represents the natural adsorption behavior of the untreated Miami colloid. Its peculiar shape indicates that there are two agencies responsible for retention of phosphate anions (10) by inorganic soil colloids where the basic cation is sodium, namely, iron compounds which are most active below pH 5.0 and clay minerals of the aluminosilicate type which exhibit maximum fixation in the vicinity of pH 6.2 to 6.3. Curves B and C represent the same colloid previously treated to reduce and remove the free iron oxides by the biological and the chemical methods, respectively. Insofar as iron compounds are a factor in phosphate fixation, attention is directed to portions of these curves lying below pH 5.0. Where only 5 millimols of H_3PO_4 were used, the removal of free iron oxides by both the chemical and biological method considerably reduced the ability of the Miami colloid to fix phosphate anions, with a slight advantage for the latter method (curve B vs. curve C). In the presence of much larger amounts of H_3PO_4 (30 m.mol.), the fixing power of this colloid was not greatly lowered by either of the treatments to remove iron oxides. Regard-

less of this fact, there is a slight advantage for the biological method over the chemical method (curve B vs. curve C) below pH 3.8, even though this advantage did not hold between pH 3.8 and 5.0. Thus, it appears from the data that the two methods are about equally effective in removing free iron oxides from inorganic soil colloids as measured by phosphate fixation studies.

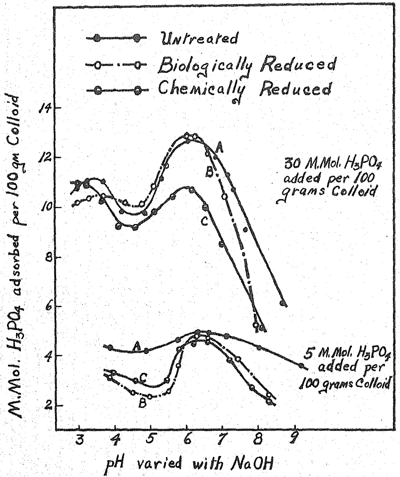


FIG. 1.—Curves of phosphate fixation by electrodialyzed Miami colloidal clay to illustrate the relative efficiency of a biological and a chemical method for removing free iron oxides.

It is of further interest to observe that phosphate fixation at pH 6.3 for the low H_3PO_4 level was quite similar, being 4.9, 4.8, and 4.6 millimols per 100 grams for the untreated, biologically reduced, and chemically reduced samples of Miami colloid, respectively. In contrast to this similarity of behavior at the lower phosphate level, the fixing

power of the chemically reduced colloid at the higher (30 m. mol.) phosphate level was considerably lower (10.7) at pH 6.3 than that of either the untreated (12.6) or the biologically reduced colloid (12.8). This difference suggests that the chemical treatment to remove iron oxides is more drastic in its effect on alumino-silicate minerals than is the biological method.

EFFECT OF REMOVING FREE IRON OXIDES ON BASE EXCHANGE CAPACITY

The colloidal clays used for this study were isolated from the B horizon of three extensively developed Indiana soil types, namely, the Miami, Cincinnati, and Frederick silt loams. In the order mentioned they represent soils developed from young glacial drift (Wisconsin), old glacial drift (Illinoian), and impure (cherty) limestone, respectively. The exchange capacity determinations were made on both the natural and the iron oxide-free clays by the titration method of Bradfield and Allison (2).

A close examination of the data in Table 2 reveals that the removal of iron oxide coatings by the chemical and biological methods facilitates the exchange reaction between the lattice ions and those of the replacing solution. The Frederick colloid, which is the most highly weathered in this group, exhibited an increased exchange capacity of 79%, as compared with an increase for the intermediately weathered Cincinnati colloid of 39.4% and for the youthful Miami colloid of 36%. This phenomenon was also observed by Truog (13) on a Cecil clay soil, for which he reported an increase in exchange capacity of from 5.6 to 6.4 M.E. per 100 grams for the A horizon and from 6.8 to 7.5 M.E. for the B horizon, respectively, as a result of iron oxide removal by the chemical procedure. On the other hand, he obtained decreases for Carrington silt loam, Miami silt loam, and a Hawaiian laterite similarly treated. Truog inferred that these differences can be attributed to the fact that the latter soils probably lost considerable of their iron base exchange material (hydrated iron silicates) due to the chemical treatment employed to remove iron oxides, which would naturally lower their exchange capacity, whereas

TABLE 2.—*Base exchange capacity of colloidal clays as affected by removal of free iron oxides.*

Colloidal clay	Total Fe_2O_3 in 100 grams of colloid, grams	Free iron oxides removed		Base exchange capacity M.E. per 100 grams	Increase in base exchange capacity %
		%	Method		
Miami	10.51	None	——	64.0	——
		23.8	Biological	87.0	36.0
		21.9	Chemical	84.0	31.2
Cincinnati	12.10	None	——	45.6	——
		36.8	Biological	63.6	39.4
Frederick	10.40	None	——	35.1	——
		47.4	Biological	62.8	79.0

the Cecil soil, being old and highly weathered, was thought to be low or devoid of iron exchange material, and that in this case removal of iron oxides actually facilitated the exchange reaction. Toth (12), working with colloids isolated from New Jersey surface soils and subsoils, reported a slight decrease in exchange capacity when free iron oxides were removed by the method of Drosdoff and Truog (4).

Kelley and Jenny (6) have indicated the necessity of physical accessibility of the exchange positions of the clay minerals lattice to the replacing ion in order for the base exchange reaction to take place. In view of this fact and of the data presented in Table 2, it is altogether conceivable that an appreciable number of the exchange positions within the clay lattice structure, especially in strongly weathered soils, is rendered inaccessible to replacing ions by the interfering iron oxides which so abundantly coat the micellar surfaces.

THE BIOLOGICAL METHOD AS A TEACHING DEVICE

In the opinion of the authors the biological procedure herein described offers an excellent teaching device for demonstrating to students the nature of reducing processes produced by soil microorganisms. It suggests the role of organic matter and environment in affecting soil changes, especially in regard to iron compounds which are important both in plant nutrition and soil genesis (podsolization). The method is simple and direct and the results are easily observed and even measurable if necessary. For laboratory teaching purposes it may be desirable to select soils or subsoil materials which are quite well oxidized (reddish colored) and which reduce readily by this process.

It will add to the interest of the demonstration to use soils that are low in organic matter and have one sample submerged under water that does not have the carbohydrate (energy material) added to it. The contrast in the activity brought about by the microorganisms supplied with the carbohydrate shows clearly that reduction in soils does not occur merely from poor drainage, waterlogging, or the lack of oxygen, but must be associated with organic matter that furnishes the energy for the microorganisms.

A more general recognition by the agronomist of the microbial processes in soils and their dependence upon available energies should at least increase his appreciation of the science with which he works and might sometime give him a new idea in approaching an unsolved problem.

SUMMARY

1. A method is described for the removal of "free" iron oxides from soils and colloidal clays which employs the principle of microbial reduction and subsequent solution.

2. The effectiveness of this method was determined by comparing it with the chemical method described by Truog, *et al.*, and with the untreated colloidal clays.

3. The removal of iron oxide coatings from colloidal clays increased their base exchange capacities in proportion to the amount of this constituent removed.

4. Aside from being a helpful research technic, the biological method, herein described, is a valuable teaching device for demonstrating the relationship between energy materials and important soil transformations, a relationship that is frequently not fully appreciated.

LITERATURE CITED

1. BENEDICT, S. R., and THEIS, R. C. A modification of the molybdic acid method for the determination of inorganic phosphorus in serum. Jour. Biol. Chem., 61:63–66. 1924.
2. BRADFIELD, R., and ALLISON, W. B. Criteria of base saturation in soils. Trans. Int. Soc. Soil Sci., A:63–79. 1933.
3. CHANDLER, W. V. Phosphorus adsorption by five Alabama soils as influenced by reaction, base saturation and free sesquioxides. Jour. Amer. Soc. Agron., 33:1–12. 1941.
4. DROSDOFF, M., and TRUOG, E. A method for removing and determining the free iron oxide in soil colloids. Jour. Amer. Soc. Agron., 27:312–17. 1935.
5. GRUNER, J. W. The origin of sedimentary iron formation, etc. The Biwabik formation of the Mesabi range. Econ. Geol., 17:407–460. 1922.
6. KELLEY, W. P., and JENNY, HANS. The relation of crystal structure to base exchange and its bearing on base exchange in soils. Soil Sci., 41:367–382. 1936.
7. KINDLER, A. Bemerkungen uber die Bildung einiger Eisenerze. Poggendorff's Ann. Phy. u. Chem., 37:203–206. 1836.
8. LIESKE, R. Untersuchungen uber die Physiologie eisenpeichernder Hypomyceten. Jahrb. Wiss. Bot., 50:328–354. 1912.
9. METZGER, W. H. Significance of adsorption, or surface fixation, of phosphorus by some soils of the prairie group. Jour. Amer. Soc. Agron., 32:513–526. 1940.
10. SCARSETH, G. D. The mechanism of phosphate retention by natural alumino-silicate colloids. Jour. Amer. Soc. Agron., 27:596–616. 1935.
11. STARKEY, R. L., and HALVERSON, H. O. The transformation of iron in nature. II. Concerning the importance of microorganisms in the solution and precipitation of iron. Soil Sci., 24:381–402. 1927.
12. TOTH, S. J. The effect of iron oxide removal on some properties of soil colloids. Soil Sci., 48:385–401. 1939.
13. TRUOG, E., *et al.* Procedure for special type of mechanical and mineralogical soil analysis. Soil Sci. Soc. Amer. Proc., 1:101–112. 1937.
14. WINOGRADSKY, S. Ueber Eisenbakterien. Bot. Ztg., 46:262–270. 1888.
15. WRIGHT, D. JR. Equilibrium studies with certain acids and minerals and their probable relation to decomposition of minerals by bacteria. Calif. Univ. Pub. Agr. Sci., 4:245–337. 1922.

THE INFLUENCE OF FERTILIZERS AND SEASON ON NONSYMBIOTIC NITROGEN FIXATION IN BROOKSTON AND BEDFORD SILT LOAMS[1]

JAMES L. ROBERTS AND FRANK R. OLSON[2]

ON most Indiana soil types, greater crop yields are obtained following fertilization with phosphorus and potassium. Greater yields of nonleguminous crops are expected to hasten depletion of soil nitrogen. However, in five of seven fields of the Purdue Experiment Station, the total nitrogen content of fertilized plots is significantly higher than that of unfertilized plots. Since the amounts and kinds of fertilizers used on the experimental plots in general are representative of practices used by Indiana farmers, these facts suggest that the use of non-nitrogenous fertilizers by farmers, even in relatively small amounts, may stimulate nitrogen fixation, either symbiotic, nonsymbiotic, or both.

It is well known that the addition of phosphates to soil samples may increase growth and nitrogen fixation by *Azotobacter* spp., this being the basis of the Winogradsky test for phosphorus deficiency. Turk (7)[3] reported that KCl added in the laboratory slightly increased the rate of nonsymbiotic nitrogen fixation in some Michigan soils.

The nitrogen-fixing power of soils variously fertilized in the field with amounts of fertilizers commonly used in farm practice has been determined on other occasions (1). If the soil is sufficiently deficient in phosphorus, the addition of even small amounts of phosphates to field soils is expected to increase the nonsymbiotic nitrogen-fixing power of the soil. There does not seem to be a case reported where a potassic salt added to field soils in relatively small amounts definitely influenced the nonsymbiotic nitrogen-fixing power of the soil.

METHODS

In 1938 and 1939, selected plots on Bedford silt loam at Bedford, Ind., and on Brookston silt loam, at Lafayette, Ind., were studied. On Bedford silt loam permanent fertility plots receiving the following six treatments were studied: (a) No treatment; (b) lime; (c) lime and phosphorus; (d) lime, phosphorus, and potassium; (e) lime, nitrogen, phosphorus, and potassium; and (f) manure. The pH of the unlimed plot was about 5.2 and that of the limed plots about 6.4.

On Brookston silt loam plots in range 5 receiving the following six treatments were studied: (a) No treatment; (b) crop residues; (c) crop residues and phosphorus; (d) crop residues, phosphorus, and potassium; (e) crop residues, nitrogen, phosphorus, and potassium; and (f) manure. All the plots at Lafayette are at approximately a pH of 6.4.

[1]Contribution from the Departments of Botany and Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. Journal Paper No. 8, of the Purdue University Agricultural Experiment Station. Received for publication March 5, 1942.

[2]Associate in Botany and Assistant in Agronomy and Botany, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 627.

The rotation used at Lafayette and Bedford is corn, soybeans, wheat, and mixed hay. The design of the experimental plots is such that all crops of the rotation occur on every treatment each year. A more detailed description of the Lafayette plots is given by Wiancko, Mulvey, and Miles (9) and of the Bedford plots by Wiancko, Walker, and Hall (8). The series of plots in corn on both soil types were sampled during 1938. Two series of plots in corn and in soybeans were sampled during 1939.

The nitrogen content of the fertilized plots on Bedford silt loam is higher than that of unfertilized plots, although more nitrogen has been removed from the fertilized plots by harvests. On Brookston silt loam neither the nitrogen content of the plots nor the amount of nitrogen removed by harvests has been appreciably influenced by fertilizer treatments.

Samples were taken from the upper 6 inches of soil at eight locations within each plot five times during each of the two years. These were composited, screened, and 15-gram (oven-dry basis) aliquots placed into each of four test tubes. Two tubes of soil were left untreated and two were treated with 2% d-mannitol. The moisture content of both soils was adjusted to 30% by weight, which was approximately 66% of the moisture-holding capacity. Gain or loss in total nitrogen was determined after 1 month of incubation in seed germinators at 30° C. During incubation, a small amount of moisture was lost from the soils.

RESULTS

INFLUENCE OF FERTILIZER TREATMENT ON RATE OF NONSYMBIOTIC NITROGEN FIXATION

The average amount of nitrogen fixed in variously fertilized plots at Bedford and at Lafayette is shown in Table 1. Each value in the table is a mean of determinations on 15 samples taken during 1938 and 1939. These averages show all pertinent information since there is no significant interaction involving fertilizers in the experiment.

TABLE 1.—*Influence of fertilizers on nonsymbiotic nitrogen fixation in Bedford and Brookston silt loams.*

Soil type	Mannitol added, %	Mgs of N gained or lost in 100 grams of soil from plots treated as indicated						Significant difference (5% level)
		0	Residues	Residues +P	Residues +PK	Residues +NPK	Manure	
Brookston silt loam	None	+0.4	−0.3	−0.2	+0.4	−0.3	+0.9	1.8
	2	+3.7	+2.7	+5.6	+2.7	+2.8	+4.0	1.8
		O	L	LP	LPK	LNPK	Manure	
Bedford silt loam	None	−0.8	−2.3	−1.8	−1.8	−1.3	−2.4	2.4
	2	+3.0	+0.8	+1.6	+1.9	+2.2	+1.1	2.4

There was no statistically significant difference in the nitrogen-fixing rates of variously fertilized plots on Bedford silt loam either when mannitol was added or when the soil was incubated without mannitol. On Brookston silt loam there were no differences between

plots sufficiently large to be significant unless mannitol was added to the soil. If mannitol were supplied, the nitrogen-fixing rate of soil from the residue-phosphorus plot was significantly higher than from the plots receiving residues alone or residues with phosphorus and potassium. It is worthy of note that phosphorus increased the rate of nitrogen fixation, whereas phosphorus with potassium did not.

Thornton (6) and others (2, 3) have shown that uptake by plants of added phosphates is increased by additions of potassic salts to certain soils. It seems possible, therefore, that the added phosphate in the residue-phosphorus-potassium plot is being more rapidly utilized by plants than in the residue-phosphorus plot. Thus, less phosphate would be available for use by nonsymbiotic nitrogen-fixing bacteria in the residue-PK plot than in the residue-P plot.

Azotobacter plaque tests for the phosphorus content of these two plots indicate that both are deficient in phosphorus and in Azotobacter. During 1938, Azotobacter counts were made and all plots on both soil types were found either to contain no Azotobacter or at most very few cells. This makes it appear likely that the nonsymbiotic nitrogen fixation observed has been due to organisms other than Azotobacter.

It is of interest to note that when a source of energy is added phosphorus stimulated nonsymbiotic nitrogen fixaton on Brookston silt loam but not on Bedford silt loam. As previously stated, analyses of the field soils for total nitrogen content indicate that phosphorus has increased nitrogen fixation in Bedford silt loam but not in Brookston silt loam. From this it must be assumed that nonsymbiotic nitrogen fixation is not responsible for the fact that on Bedford silt loam, plots receiving phosphorus or phosphorus and potassium have a higher total nitrogen content than unfertilized plots in spite of greater removal of nitrogen by nonleguminous crops on the fertilized plots.

SEASONAL CHANGE IN RATES OF NONSYMBIOTIC NITROGEN FIXATION

Table 2 shows seasonal change in the rates of nitrogen fixation in the two soils. Each value in the table is the average of 18 determinations. Seasonal variation is appreciable.

TABLE 2.—*Seasonal variation in nonsymbiotic nitrogen fixation rates in Bedford and Brookston silt loams.*

Soil type	Per cent mannitol added	Mgs of N gained or lost in 100 grams of soil sampled at indicated date ranges					Significant difference (5% level)
		Mar. 30 – Apr. 13	May 20 – June 7	Aug. 9 – Aug. 25	Sept. 27 – Oct. 4	Nov. 25 – Nov. 30	
Brookston silt loam	None	−2.6	+3.3	+4.8	+0.2	−5.0	1.6
	2	+1.4	+6.9	+7.2	+3.3	−0.9	1.7
Bedford silt loam	None	−1.8	+2.6	−0.9	−1.6	−6.9	2.2
	2	+2.2	+4.8	+2.8	+2.3	−3.3	2.2

Although Thompson (5), Thomas and Elliott (4), and perhaps others, have previously shown that seasonal changes in rates of nitrogen fixation do occur, this fact seems not to have received due consideration in subsequent studies. When factors affecting nonsymbiotic nitrogen fixation in soil are studied, the season at which soil samples are taken from the field may be of considerable importance in determining the nature of the results obtained.

SUMMARY

The rates of nonsymbiotic nitrogen fixation in variously fertilized plots on Bedford and Brookston silt loams were determined during 1938 and 1939. From the results obtained, the following conclusions are drawn:

1. The higher soil nitrogen content of the fertilized Bedford silt loam, as compared with unfertilized, is not due to stimulated nonsymbiotic nitrogen fixation.
2. Phosphatic and potassic fertilizers had no influence on rates of nonsymbiotic nitrogen fixation in Bedford or Brookston silt loams. However, if mannitol were added to Brookston silt loam, plots fertilized with phosphorus were found to have a higher rate of nonsymbiotic nitrogen fixation than the unphosphated plots. This was not the case with Bedford silt loam.
3. Relatively few Azotobacter were found in the samples studied and can not be judged responsible for a significant portion of the observed nitrogen fixation.
4. There was considerable seasonal variation in rates of nonsymbiotic nitrogen fixation in each of the soils studied.

LITERATURE CITED

1. BATCHELOR, H. W., and CURIE, I. H. The Nitrogen-fixing flora of the five-year rotation fertility plots. Ohio Agr. Exp. Sta. Bul. 470. 1931.
2. SPURWAY, C. H. Some factors influencing the solubility of phosphorus in soil-acid phosphate mixtures. Soil Sci., 19:399-405. 1925.
3. THOMAS, W. The reciprocal effects of nitrogen, phosphorus, and potassium on the adsorption of these elements by plants. Soil Sci., 33:1-20. 1932.
4. THOMAS, B., and ELLIOTT, F. J. The effect of manurial treatment on nitrogen fixation and nitrification in certain experimental plots. Jour. Soc. Chem. Ind., 51:332T-336T. 1932.
5. THOMPSON, L. G. The periodism of nitrogen fixation in soils and the influence of inoculation with Azotobacter. Jour. Amer. Soc. Agron., 24:442-451. 1932.
6. THORNTON, S. F. Soil and fertilizer studies by means of the Neubauer method. Purdue Univ. Agr. Exp. Sta. Bul. 399. 1935.
7. TURK, L. M. Studies of nitrogen fixation in some Michigan soils. Mich. Agr. Exp. Sta. Tech. Bul. 143. 1935.
8. WIANCKO, A. T., WALKER, G. P., and HALL, H. G. Progress report of soils and crops experiments on the Bedford Experiment Field from 1916-1940. Purdue Univ. Agr. Exp. Sta. Circ. 243 (Revised). 1941.
9. ———, MULVEY, R. R., and MILES, S. R. Progress report of the Soils and Crops Experiment Farm from 1915-1940. Purdue Univ. Agr. Exp. Sta. Circ. 242 (Revised). 1941.

THE RELATIONS TO YIELD OF CERTAIN PLANT CHARACTERS OF WINTER WHEAT AS INFLUENCED BY DIFFERENT TILLAGE AND SEQUENCE TREATMENTS[1]

L. F. LOCKE, O. E. RAUCHSCHWALBE, AND O. R. MATHEWS[2]

MANY years of experimental work in the Great Plains have demonstrated that tillage treatments and crop sequences materially affect yields of winter wheat, but the manner in which these yield differences are related to the development of the wheat plant has received very little attention. The study reported herein was made to obtain information as to these relations. Yield records in the crop rotation and tillage experiments at Woodward, Okla., had shown that differences in winter wheat yields could be expected from given differences in cultural treatment and crop sequence.

It was definitely known, for example, that on continuously cropped wheat land, average yields were higher where cultivation for the succeeding crop was started shortly after harvest than where it was delayed until fall; that average yields were higher on corn ground and cowpea ground than on milo or kafir ground; and that average yields on fallowed land were higher than on land where a crop had been grown. Differences in the quantity of water available for the crop under the different treatments were known to be sufficient to account for most of these differences in yield; but how the plant populations or the individual plants were affected was not known. The purpose of the experiment described here was to obtain information on this point. A study of sampling methods and of forecasting yields was not in mind when these investigations were undertaken, although some of the results appear to have an incidental relation thereto.

MATERIALS AND METHODS

The studies reported herein were made at the Southern Great Plains Field Station, Woodward, Okla., from 1929 to 1934. The plots on which the observations were made are 1/10 acre in size and are located in a field used for the study of the effect of rotation and tillage methods on crop yields. The plots where wheat was grown continuously by different tillage methods were the same from year to year. The results from each row crop or fallow rotation are from two plots on which wheat is grown in alternate years. Turkey winter wheat was planted in late September or early October in all years, the seeding for all plots being on about the same date and at the same rate. The same drill, also, was used on all plots except those where wheat followed sorghums. In some years when wheat was seeded before the sorghums were harvested, seeding was done with a disk drill narrow enough to pass between the sorghum rows. No winterkilling, stem rust, or other unusual disease or weather losses occurred during the period of study.

[1]Contribution from the Bureau of Plant Industry, U. S. Dept. of Agriculture. The senior author started the studies reported herein, when he was in charge of the crop rotation and tillage method field experiments at the Southern Great Plains Field Station, Woodward, Okla. Received for publication March 18, 1942.

[2]Associate Horticulturist, Junior Statistician, and Senior Agronomist, respectively.

The soil on which these plots were located is classed as Pratt fine sandy loam. This soil has a relatively low water-holding capacity and consequently differences in water storage due to treatment are not so pronounced in wet as in dry years.

Eleven plots, differing in tillage or in the preceding crop, were selected on which to study plant characters. The treatments for each plot were as follows:

Plot or rotation	Treatment
A	Continuous winter wheat, late (September) shallow fall-plowed between crops.
B	Continuous winter wheat, early (July) deep fall-plowed between crops.
C/D	Winter wheat on land fallow one season previous to seeding.
F	Continuous winter wheat, early (July) listed between crops.
X	Continuous winter wheat, disked late (September) between crops.
Y	Continuous winter wheat, early (July) shallow fall-plowed between crops.
Z	Continuous winter wheat, early (July) disked between crops.
262	Winter wheat on disked corn ground.
263	Winter wheat on disked milo ground.
264	Winter wheat on disked kafir ground.
265	Winter wheat on disked cowpea ground.

The entire plots were harvested, but each year before harvest four quadrats, each 3.3 feet square, were taken from each plot for a study of plant characters. The positions of the quadrat samples in the plots were non-random but systematically representative with one quadrat taken from each quarter plot. The sampling procedure was modified by judgment to avoid untypical effects, such as double plantings where the drill overlapped or from skips in the drill row.

The plant numbers were recorded for the entire quadrats. Observations of plant characters were made on 25 plants taken at random from each quadrat, or a total of 100 plants from each 1/10-acre plot. Random selection was effected by spreading out the plants from each quadrat and taking every other one until 25 plants had been selected.

The primary data obtained from the samples were height of plants in inches, number of heads, length of heads, number of spikelets, number of kernels, and weight of kernels. From these basic data the number of heads per plant and per unit area; the number of spikelets per head, per plant, and per unit area; the number of kernels per spikelet, per head, and per unit area; and the weight of 1,000 kernels were obtained by calculation. Yields per acre were obtained by harvesting the whole plot and also by calculation from the quadrat samples.

EXPERIMENTAL RESULTS

The yields as determined from the entire plots and from the quadrat samples, together with the differences between them, are presented in Table 1. In this table, the yields from the entire plot have been adjusted for an assumed 6.1% binder loss for 1929 to 1931 and for a 2.5% combine loss for 1932 to 1934 (3).[3] Averages are included primarily for a later comparison with plant characters. As noted above, the objective was not to study sampling procedures and the comparisons in this table should be regarded as incidental to the

[3]Figures in parenthesis refer to "Literature Cited", p. 645.

main purpose, which was to study the relation between plant characters and yield. It is nevertheless of interest to note that the yields

TABLE 1.—*Yield in bushels per acre determined from four 25-plant samples and from harvesting whole plots and the differences between them for treatment and year, 1929 to 1934.*

Source	Treatment											
	A	B	C/D	F	X	Y	Z	262	263	264	265	Av.
						1929						
Sample	8.1	15.4	17.2	11.6	9.9	17.9	18.8	23.1	25.4	28.7	23.9	18.2
Plot	6.9	13.1	12.6	11.2	6.9	20.8	13.8	24.8	21.6	25.0	26.8	16.7
Diff.	1.2	2.3	4.6	0.4	3.0	−2.9	5.0	−1.7	3.8	3.7	−2.9	—
						1930						
Sample	10.6	17.1	19.5	16.6	8.8	25.4	16.1	21.1	8.8	16.6	12.8	15.8
Plot	7.2	21.5	23.6	17.4	6.6	23.1	15.7	18.3	6.2	13.5	13.3	15.1
Diff.	3.4	−4.4	−4.1	−0.8	2.2	2.3	0.4	2.8	2.6	3.1	−0.5	—
						1931						
Sample	12.2	20.9	31.1	21.0	20.0	29.5	24.2	23.8	18.1	18.4	20.8	21.8
Plot	12.6	25.3	29.3	20.4	17.8	27.4	23.7	24.8	13.3	14.2	22.2	21.0
Diff.	−0.4	−4.4	1.8	0.6	2.2	2.1	0.5	−1.0	4.8	4.2	−1.4	—
						1932						
Sample	17.1	24.2	22.9	22.5	15.7	19.0	24.4	25.4	15.1	27.1	18.3	21.1
Plot	13.3	21.0	27.4	21.8	18.7	24.4	21.3	23.9	16.2	20.8	22.6	21.0
Diff.	3.8	3.2	−4.5	0.7	−3.0	−5.4	3.1	1.5	−1.1	6.3	−4.3	—
						1933						
Sample	1.8	10.1	10.2	9.5	2.9	10.9	10.8	7.5	3.0	4.7	5.9	7.0
Plot	1.7	9.7	8.4	9.5	2.3	12.0	10.5	7.0	2.4	3.6	4.8	6.5
Diff.	0.1	0.4	1.8	0.0	0.6	−1.1	0.3	0.5	0.6	1.1	1.1	—
						1934						
Sample	7.8	21.3	29.5	13.4	5.7	8.2	15.3	5.3	5.3	3.1	9.8	11.3
Plot	4.9	15.4	23.9	14.1	5.4	7.9	12.0	7.9	6.2	3.4	10.4	10.1
Diff.	2.9	5.9	5.6	−0.7	0.3	0.3	3.3	−2.6	−0.9	−0.3	−0.6	—
						Average						
Sample	9.6	18.2	21.7	15.8	10.5	18.5	18.3	17.7	12.6	16.4	15.3	—
Plot	7.8	17.7	20.9	15.7	9.6	19.3	16.2	17.8	11.0	13.4	16.7	—

as determined by harvesting the entire plot and those estimated from the quadrats agree remarkably well. The differences between sample and plot yields are normally distributed. On only one treatment, 264, were the differences consistent enough to make a material difference between average plot and sample yields.

Differences in yield between seasons were thought to have been due largely to differences in precipitation and evaporation. The correlation coefficients for yield and precipitation for the crop year June to May and for yield and evaporation for the growing season April to June, accordingly, were calculated. The coefficient for the first relation was found to be .385 and for the second −.839. The multiple correlation coefficient was .874. It would thus appear that 75% or more of the yearly variation in yield may be attributed to differences in these two climatic factors.

The average number of plants per unit area (0.001 acre) for each treatment each year, for all treatments each year, and for all years for each treatment, together with similar data for heads per plant, spikelets per head, kernels per head, length of head, plant height, and weight per 1,000 kernels are given in Table 2. These particular data are presented in detail because it is thought that they would be of most interest to anyone wishing to make further use of them. The characters not given can be computed from those given in this table.

The high number of plants per unit area for treatments 263 and 264 in 1931 was probably due to the drill used. Wheat was planted between the sorghum rows before the sorghum was harvested, and the number of plants per unit area indicate that the seeding rate must have been much higher than on other plots.

It will be at once apparent that there were marked differences in the plant characteristics shown in Table 2 and in yield (Table 1) both with respect to year and treatment. The significance of these differences will be shown by correlations and by the analysis of variance.

PLANT CHARACTERS AND YIELD

The individual relations between plant characters and yield were first studied by means of scatter diagrams and coefficients of correlation. So far as could be determined and with minor exceptions to be mentioned later, the regressions were essentially linear.

In most cases the relation between plant characters and yield were not the same for all years nor for all treatments. That is, the slopes of the regression lines, or the points of origin, or both, were different. In order to avoid spurious deductions, the relations must be considered separately for each year and treatment, or the correlation coefficients must be calculated with year and treatment differences removed. Since the separate studies involved are too numerous to present in detail and since the purpose of this paper is to consider the relations as a whole, the latter expedient was adopted. For this purpose, the treatment and season sums of squares were isolated as explained by Snedecor (4). The calculations provide four sets of correlation coefficients, *viz.*, (a) unadjusted coefficients, (b) with seasonal differences removed, (c) with treatment differences removed,

TABLE 2.—*Plant observations by treatment and season.*

Year	Treatment											
	A	B	C/D	F	X	Y	Z	262	263	264	265	Av.
						Plants per Unit Area						
1929	791	759	959	890	809	777	810	590	699	722	636	767
1930	667	611	693	674	559	648	635	555	567	666	635	628
1931	396	627	506	667	848	583	599	404	1349	1306	479	706
1932	762	805	906	912	709	894	915	792	644	645	931	810
1933	317	446	346	302	351	453	433	433	487	588	301	405
1934	435	563	599	508	468	494	500	474	360	351	665	493
Av.	561	635	668	659	624	642	649	542	684	713	608	635
						Heads per Plant						
1929	1.38	1.73	1.53	1.46	1.58	2.12	1.94	3.00	2.68	2.73	2.63	2.07
1930	1.53	2.35	2.37	2.15	1.72	2.76	2.21	2.74	1.35	1.85	2.05	2.10
1931	2.05	1.95	3.28	2.19	1.73	3.01	2.49	3.33	1.19	1.16	2.75	2.28
1932	2.03	2.36	2.33	2.03	2.11	2.01	2.13	2.54	1.75	2.91	2.04	2.20
1933	1.07	1.76	2.53	2.13	1.27	2.10	1.77	1.48	1.11	1.06	1.42	1.61
1934	1.58	3.21	4.32	2.92	1.66	2.40	3.07	2.98	2.40	2.73	2.29	2.69
Av.	1.61	2.23	2.73	2.15	1.68	2.40	2.27	2.68	1.75	2.07	2.20	2.16
						Spikelets per Head						
1929	6.75	8.05	7.46	6.96	6.66	9.56	8.29	8.81	8.94	8.93	8.51	8.08
1930	7.50	9.02	8.71	8.41	7.18	9.50	8.45	9.04	7.43	9.07	8.53	8.44
1931	10.33	11.56	11.48	9.68	8.62	11.08	10.39	10.44	7.85	7.91	9.27	9.87
1932	8.00	9.10	8.60	8.70	8.30	8.60	8.80	9.60	8.70	9.90	8.80	8.83
1933	6.40	11.60	11.50	13.00	8.30	12.10	12.50	10.60	7.40	7.50	11.30	10.20
1934	7.90	10.50	11.90	12.10	11.30	12.10	11.10	10.00	11.00	11.70	11.30	10.90
Av.	7.81	9.97	9.94	9.81	8.39	10.49	9.92	9.75	8.55	9.17	9.62	9.39
						Kernels per Head						
1929	9.9	15.3	14.1	11.6	11.1	14.4	14.7	15.7	16.1	17.7	16.4	14.3
1930	10.8	12.3	12.2	13.0	10.6	14.9	12.5	14.4	11.8	13.9	12.4	12.6
1931	17.0	20.1	19.9	16.4	15.3	18.6	18.0	18.1	13.2	13.5	15.9	16.9
1932	11.2	13.4	11.7	12.7	12.1	12.8	15.1	14.7	14.1	16.4	11.1	13.2
1933	8.5	19.7	17.0	22.5	10.7	18.3	20.3	16.6	10.2	11.0	18.2	15.7
1934	13.6	13.7	13.2	10.4	9.7	7.8	11.0	4.1	6.3	4.2	6.7	9.2
Av.	11.8	15.8	14.7	14.4	11.6	14.5	15.3	13.9	12.0	12.8	13.5	13.7
						Weight per 1,000 Kernels, Grams						
1929	21.51	22.03	24.04	22.17	20.11	21.74	23.43	24.04	24.27	23.80	25.25	22.94
1930	27.62	27.93	28.09	25.45	24.93	27.55	26.53	27.70	28.02	28.09	22.83	26.79
1931	25.46	24.52	27.27	25.31	25.66	26.05	26.00	28.14	24.71	26.01	28.63	26.16
1932	28.45	27.47	26.88	27.59	25.13	23.76	24.01	24.72	27.36	25.38	25.03	25.98
1933	18.35	18.87	19.82	18.95	17.77	18.11	20.01	20.33	15.85	19.69	22.11	19.08
1934	23.98	24.78	24.97	25.16	22.10	25.44	26.04	26.49	28.09	22.53	27.89	25.22
Av.	24.23	24.27	25.18	24.11	22.62	23.78	24.34	25.24	24.72	24.25	25.29	24.36

TABLE 2.—*Concluded.*

Year	Treatment											
	A	B	C/D	F	X	Y	Z	262	263	264	265	Av.
					Length of Heads, Inches							
1929	1.45	1.68	1.57	1.47	1.45	1.60	1.66	1.91	1.92	1.96	1.86	1.68
1930	1.42	1.79	1.77	1.67	1.40	1.74	1.67	1.79	1.46	1.75	1.66	1.65
1931	1.90	2.09	2.16	1.86	1.71	2.04	2.01	2.01	1.49	1.54	1.81	1.78
1932	1.49	1.72	1.62	1.65	1.51	1.66	1.62	1.82	1.58	1.92	1.64	1.66
1933	1.51	2.51	2.69	2.85	1.96	2.74	2.84	2.38	1.77	1.87	2.46	2.33
1934	1.88	2.34	2.55	2.38	2.08	2.29	2.34	2.25	2.44	2.48	2.39	2.31
Av.	1.61	2.02	2.06	1.98	1.68	2.01	2.02	2.03	1.78	1.92	1.97	1.91
					Plant Height, Inches							
1929	21.4	26.3	24.1	25.0	22.3	31.2	27.8	33.6	31.2	34.7	32.5	28.2
1930	20.4	26.6	26.6	26.0	21.5	28.1	24.6	25.7	21.9	23.6	21.9	24.3
1931	25.2	31.1	34.5	29.2	24.8	34.4	31.3	31.2	23.6	23.4	29.2	28.9
1932	21.8	26.0	27.0	26.3	23.5	25.7	25.0	24.4	22.9	23.7	22.8	24.4
1933	13.1	22.0	20.3	24.7	15.7	23.4	24.2	19.6	15.3	14.8	18.0	19.2
1934	14.9	20.2	23.4	19.5	15.7	17.2	19.5	15.9	16.0	15.0	16.5	17.6
Av.	19.5	25.4	26.0	25.1	20.6	26.6	25.4	25.1	21.8	22.5	23.5	23.8

and (d) with both seasonal and treatment differences removed. The resulting coefficients are given in Table 3.

TABLE 3.—*Correlations between different plant characters and yield.*

Factors correlated	Correlation coefficient			
	Un-adjusted	Seasons removed	Treat-ments removed	Seasons and treat-ments removed
Yield and kernels per unit area	0.9795	0.9834	0.9758	0.9751
Yield and heads per unit area	0.8571	0.8656	0.8214	0.7690
Yield and plants per unit area	0.4266	−0.0497	0.4619	−0.1440
Yield and height	0.8306	0.8220	0.8109	0.7437
Yield and weight of 1,000 kernels	0.0518	0.2811	0.5431	0.1998
Yield and head length	−0.1622	0.6014	−0.4074	0.3756
Yield and heads per plant	0.6071	0.7965	0.5010	0.7068
Yield and spikelets per head	0.0602	0.5345	−0.0607	0.2884
Yield and kernels per head	0.4910	0.6862	0.4197	0.6263
Level of significance:				
At 5% point	0.241	0.250	0.261	0.273
At 1% point	0.313	0.325	0.339	0.354

A comparison of the four coefficients for each relation will at once reveal to what extent they are affected by season and treatment. Thus, the coefficients for yield and number of kernels per unit area

are much the same whether seasonal and treatment effects are or are not removed. This means that the slopes of the regression lines were much alike, as may be seen from the data shown in Fig. 1. On the contrary, the coefficients for yield and plants per unit area varied from .4619 to −.1440 and those for yield and head length from .6014 to −.4074 for the reason that the regressions for different years and different treatments were very different. The fact that some of the coefficients are quite different depending on the removal of season and treatment effects would appear to be of special significance in relation to any attempts to estimate yield from plant characters, since different formulae would be required for each situation.

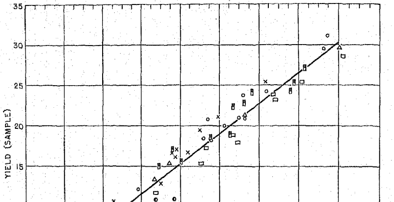


FIG. 1.—Scatter diagram of number of kernels per unit area and yield of winter wheat at Woodward, Okla.

On the whole, the coefficients for "seasons removed" indicate the degree to which yield between different treatments can, on the average, be explained by the character in question, and those for "treatments removed" the degree to which yield between years can be explained where such differences exist.

The coefficients of predominating interest in Table 3 are those for kernels per unit area and yield. Since the lowest is .9751, we can say that more than 95% of the variation in yield is explained by this character alone. The standard error of estimate is 1.54 bushels. The relationship for number of heads and yield is also very high. The lowest correlation coefficient is .7690, and it is, therefore, indicated that almost 60% of the variation in yield is explained by number of heads alone. Likewise, the coefficients for yield and height are fairly high.

Other coefficients are generally low or are variable depending on the removal of season and treatment differences.

Since yield is a function of number of kernels per unit area and weight per kernel (weight per 1,000 in Table 3), it is of interest to note that in these studies number of kernels was much more important in determining yield than was weight of kernel. Severe damage from rust, scab, frost, or complete premature soil-moisture exhaustion did not occur.

Because of the interrelations of the different plant characters, a study of the individual coefficients does not necessarily provide reliable estimates of their relative importance. Since yield is seldom or never determined by one character alone, multiple coefficients were calculated for those characteristics which it seemed might be most closely associated with yield. Only a part of the various possible combinations were considered, those for which calculations were made being based in part on the data of Table 3 and in part on relations known to exist. Also, some multiple correlations were calculated for certain plant characteristics that are easily determined or measured, such as plant height and number of heads.

Fig. 2 presents some of the logical or expected relations between certain plant characters and yield, the broken lines indicating characters that may be considered as alternates to those shown by the solid lines. The figures represent the percentage of the total variation in the factor at the upper end of each line that may be explained by the factor at the lower end of the line.

Since kernels per unit area explain 95% or more of the variation in yield, it is of interest to determine to what extent yield is determined by heads per unit area and number of kernels per head considered separately. The multiple coefficient for these two characters and yield was found to be .9270. This lower value as compared with approximately .98 for number of kernels alone and yield appeared to be due to a slight departure from linearity. The simple correlation between the heads per unit area and kernels per head was .1640 or essentially zero. It appears, therefore, in view of Fig. 1, that a simple multiplication of observations of the two factors to obtain the kernels per unit area would not only correct this situation but would consequently result in greater precision for yield determinations. This procedure seems especially practical because the number of kernels per head can be rather easily determined. A given number of heads may be threshed and the grain divided in two equal parts successively until a quantity that can be readily counted is reached. If the plant height is added to the multiple regression and curvilinearity in other factors ignored, the multiple correlation with seasons and treatments removed becomes .9385. It was found that the standard partial regression coefficient for height was significant, thus ordinarily indicating a contribution to the information on yield. It should also be noted here that these multiple regressions differed significantly from season to season.

It was found that for yield determinations on the basis of plant characters other than kernels, the two characters heads per unit area and plant height predominated. The ease of determination of these

two characters attaches special interest to this group. The multiple correlation not influenced by treatments and seasons is .8957. When additional factors are introduced, very little additional information on yield is obtained. If head length is added the multiple correlation coefficient becomes .8969. When still another character, plants per

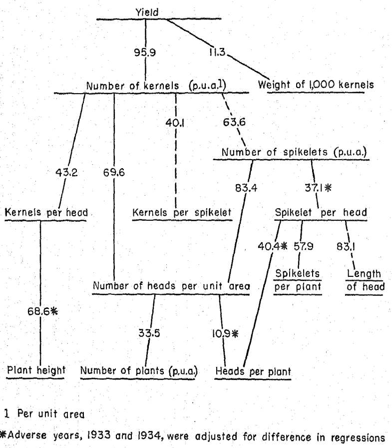


FIG. 2.—The relation of certain plant characters and yield, with the percentage of variation explained by the related items.

unit area, is employed, the coefficient is .8995. The standard partial regression coefficients indicated that the last two characters, head length and plants per unit area, were quite unimportant. A covariance analysis showed that the multiple regressions of all four characters on yield did not differ significantly among treatments. It seems, therefore, that the cultivations and rotations tested did not cause the characters to respond differently for similar yields.

ANALYSES OF VARIANCE

These analyses are made to determine how the different plant characters are affected by treatment and season differences. Analyses are made of the 6-year period as a whole and of two groups of years 1929–32 and 1933–34. In the latter period the crop on most treatments suffered considerably from drought and yields (Table 1) were generally low. The analyses for the shorter periods are made to determine whether the significance of the variance of the plant characters shown by the 6-year analysis holds true when only years of the same general type are grouped. Significance is measured by the treatment×season interaction. Results are presented in Table 4.

For the 6 years as a whole, variance for all characters was highly significant between seasons, and for all characters except kernels per head, kernels per spikelet, plants per unit area, and weight of 1,000 kernels, variance was highly significant between treatments. When the years 1933 and 1934 are separated from the other years, however, some of the characters do not show a significant response to seasonal or treatment differences in either group of years. Certain characters, such as head length and kernels per spikelet, show no significant difference between treatment for either the 4- or the 2-year period. This indicates that these characters differ little between treatments in years of the same type, but that their treatment response is different in years of different types. Plant height, on the other hand, while not always significant between seasons, showed a significant response to treatment difference in both sets of years, showing that it might be a good indicator of yield within seasons.

The heads per unit area did not differ significantly between treatments for the period 1933–34. As mentioned before, these were both seasons of drought injury, but the manner in which drought affected the plants differed. In 1933 drought continued until harvest, and the relatively small number of heads all matured. In 1934 drought injury became severe in April, and in the first part of May there were many plots in which most of the plants appeared to be injured beyond recovery. Rain about the middle of May caused recovery and many plants sent up new tillers that headed much later than the old tillers. These late heads had formed little or no grain when the plots were harvested. The heads without grain in this one year greatly reduced the relationship between head number and yield.

As a whole, the analyses showed that the characters with the most significant variances were those that showed the highest correlations with yield.

GRAPHIC STUDY OF PLANT CHARACTERS

The general overall relation between yield for the various treatments and plant characters are shown graphically in Fig. 3. For this figure the years 1929 to 1932 are averaged and likewise those for 1933 and 1934, and each graphed separately to represent the behavior of the character in both favorable and unfavorable seasons. It will be noted that some of the plant characters, especially plants per unit area and height of plants, were adversely affected in the unfavorable

TABLE 4.—*Relative importance of treatment and seasonal differences of yield and certain plant characters as determined by ratio between variances and the season × treatment interaction variance.*

Factor	Period 1929–34, difference between		Period 1929–32, difference between		Period 1933–34, difference between	
	Treatments	Seasons	Treatments	Seasons	Treatments	Seasons
Yield (sample)	Highly significant*	Highly significant	Highly significant	Highly significant	Significant	Significant
Kernels per unit area	Highly significant*	Highly significant	Highly significant	Highly significant	Significant	Not significant
Spikelets per unit area	Highly significant*	Highly significant	Highly significant	Highly significant	Significant	Highly significant
Heads per unit area	Highly significant*	Highly significant	Significant	Highly significant	Not significant	Highly significant
Spikelets per plant	Highly significant*	Highly significant	Highly significant	Significant	Highly significant	Highly significant
Heads per plant	Highly significant*	Highly significant	Not significant	Not significant	Highly significant	Highly significant
Plant height	Highly significant*	Highly significant	Significant	Highly significant	Significant	Not significant
Spikelets per head	Highly significant*	Highly significant	Not significant	Highly significant	Not significant	Not significant
Length of heads	Highly significant*	Highly significant	Not significant	Highly significant	Not significant	Not significant
Kernels per head	Not significant	Highly significant	Not significant	Highly significant	Not significant	Not significant
Kernels per spikelet	Not significant	Highly significant	Not significant	Highly significant	Not significant	Not significant
Plants per unit area	Not significant	Highly significant	Not significant	Not significant	Not significant	Not significant
Weight of 1,000 kernels	Not significant	Highly significant	Not significant	Highly significant	Not significant	Highly significant

*Highly significant if F value exceeds 1% point; significant if F value exceeds 5% point but not 1% point; not significant if F value is below 5% point.

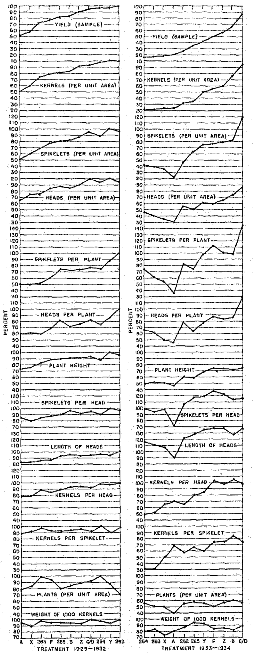


FIG. 3.—Averages of plant characters plotted by treatments in percentage of highest value of the period 1929–32 for two periods, 1929–32 and 1933–34.

seasons. It should not be assumed that the data for years within these groups were completely homogeneous, but either such differences as were present were not important so far as the present study is concerned or they are called to the reader's attention later. In this figure each variable is expressed as a percentage of that for the treatment having the highest value for the more favorable period, i.e., 1929 to 1932. Treatments are arranged on the x axis, in order of the magnitude of average yields. Thus for the 1929 to 1932 period, plot A (late shallow fall-plowed after winter wheat) is at the extreme left because it produced the lowest average yield and plot 262 (disked after corn) is at the extreme right because it produced the highest average yield. The yield of plot 262 for the 4-year period is indicated as 100% and plot A as 51.4%, since its average yield was 51.4% of that of 262. Other treatments fall in between according to their average yield. Plot Y had the highest number of spikelets per unit area, hence it is charted as 100% and the others accordingly. The period 1933 and 1934 is graphed in the same way, with each average expressed in percentage of the highest average yield for the first 4 years.

The figure shows at a glance which characters are closely related with yield. It also shows whether the range differs from the range of yield. Heads per unit area, for example, showed much the same range as yield, while plant height, although generally varying in the same direction as the yield, showed a much smaller variation between treatments.

The figure demonstrates the close agreement of kernels per unit area and yield in both sets of years but an absence of agreement between kernel weight (weight of 1,000 kernels) and yield and between plants per unit area and yield in either set of years. Most of the discrepancies between some of the plant characters and yields for the 2-year period 1933–34 are due to the difference in the way drought affected the plants in the two years. This has already been pointed out.

Fig. 3 further illustrates how the relative importance of different factors may vary in determining the yield under different treatments. It does not show, however, whether the average importance of a character is due to a smaller response in each year or to an exaggerated response in a few years. This is considered in a discussion of some individual plot comparisons.

DISCUSSION

The very high coefficients for yield and number of kernels per unit area for different treatments and especially for different years were unexpected. Earlier work by others suggests that such high coefficients cannot always be expected. Sprague (5), for example, has reported an extensive study between yield and various plant characters for winter wheat grown in Nebraska and New Jersey, and Quisenberry (2) a similar study for winter wheat grown in Oklahoma, Kansas, Nebraska, and Montana, and for spring wheat in Montana. Neither reports correlation coefficients for yields and number of kernels directly, but from other data that are given it may be inferred that,

although much of the variation in yield may be so explained, the amount is less than in the present study. Laude (1) indicates a close relation between yield and number of heads per unit area and also between yield and kernel weight for winter wheat seeded at various dates. Correlation coefficients were not reported, but here again, weight per kernel was probably more important in determining yields than in this study. It has been pointed out that conditions which would tend to give kernel weight greater importance were not present in these tests. This need not, however, curtail the value of the results obtained, because environment conducive to kernel shrivelling is not common in this region. In 22 years at Woodward the average bushel weight of the group of plots used in this study was below 60 pounds in only 5 years. Three of these 5 years are in the period covered by this study and the minimum average bushel weight in any year was 55 pounds.

A priori consideration, as well as the data presented herein, suggest that the wheat plant undergoes various adjustments to environmental conditions throughout the season. If moisture at seeding time is plentiful and the soil is in good tilth and if a uniform rate of seeding is used, no marked differences in plant number between treatments would be expected. If, on the contrary, there are differences with respect to either of these basic requirements, then differences in plant numbers between seasons and treatments would be expected. In the present study such differences were seldom extreme.

The number and the development of tillers, heads, spikelets, and kernels depend on whether environmental conditions throughout the season are favorable or unfavorable, and in part, also, on the number of plants and their development previous to the phase of development then being considered. Thus, a heavy stand will result in fewer tillers and heads per plant, and generally shorter heads than on thin stands. In this study material differences in stand were not a common occurrence, but some plots may serve as an illustration of the effects of such differences.

Winter wheat on corn ground (treatment 262) had the lowest number of plants per unit area of any treatment for the favorable years from 1929 to 1932 (Table 2 and Fig. 3) and yet produced the highest yield. The deficiency in plants per unit area was more than compensated by a high number of heads per plant, by longer heads than other treatments, and by relatively high numbers of spikelets per head and kernels per spikelet. These various adjustments enabled this treatment to reach harvest with as high a number of kernels per unit area as any treatment. Weight per kernel was a little above average and contributed slightly to making the yield of this treatment higher than that of any other.

Winter wheat on sorghum ground (263 and 264) in the single year 1931 had a very high number of plants per unit area (Table 2) for reasons previously cited. This thick stand reduced the tillering rate so that the plots produced only 1.19 and 1.16 heads per plant, respectively. Further adjustment was made by reductions in head length and in number of kernels per head, and a final slight adjustment was made by reducing the average kernel weight.

The purpose of the study, as stated earlier, was to determine in what way the different treatments affected plant characters to produce the known differences in yield. There appears to be no simple answer to the problem. While an average figure is indicative of average behavior, it is evident that characters do not react the same in all years to produce this average. In the introduction attention was called to cultural treatments between which differences in yield could be expected. A comparison of some of these in detail should prove of interest in determining which characters accounted for the yield differences, and how consistent their behavior was from year to year. It was mentioned that the average yield of the fallowed plot, C/D, was higher than that of cropped plots. A comparison of this fallowed plot with early fall-plowed plot B which adjoins plot C shows that, in general, the measurements of characters other than stand that are recorded in terms of unit areas varied in the same direction as the yield. Head characters did not show the same general agreement. In all years but one, 1932, the heads per unit area agreed with the yield. In that one year, 1932, a slightly lower number of heads on plot B was more than compensated by a higher number of kernels per head. In the other five years, however, the number of kernels per head varied in the opposite direction from the yield, indicating that differences in number of kernels per head were not ordinarily great enough to compensate for differences in head numbers.

It was also mentioned that the average yield following corn (262) was higher than following milo (263). In 4 of the 6 years the number of heads per unit area varied in the same direction as the yield. In one year, 1934, a greater number of kernels per head on treatment 263 combined with a slightly higher kernel weight and number of spikelets per head to more than compensate for the greater number of heads on treatment 262. In the other year, 1931, the previously mentioned high number of plants per unit area on treatment 263 resulted in more heads on this plot, but adjustment in head length and spikelets per head kept its yield below that of treatment 262. Two head characters, spikelets per head and kernels per head, were in the same relative position as yield in all of the 6 years. In 4 of these years, however, the difference was not material enough to exert an influence on the yield equal to that exerted by the number of heads.

A comparison of early fall-plowed plot B with late fall-plowed plot A showed a considerable difference in yield in favor of plot B in all years. All characters except plants per unit area, kernel weight, and kernels per spikelet were higher on plot B in at least 5 of the 6 years. The striking yield difference between these two plots was evidently due to a combination of nearly all characters, but the relative importance of different characters in fixing the yield varied from year to year.

These instances are given to call attention to the fact that the influence of a character, particularly a head character, on treatment differences is not the same from year to year. It was noted earlier, however, that a test of multiple regressions indicated that these individual differences did not show up significantly for the years as a whole when characters were considered in combination. Thus it

appears again that extreme treatment influences which would cause characters to compensate differently for one another among treatments were not present.

Examination of data for the individual years and of averages for the 6 years shows that the variations in head characters between treatments are small in comparison with the yield differences. Characters that are measured on the unit area basis, such as kernels per unit area and spikelets per unit area, show about the same variation as yield. The spikelets per plant and plant height vary somewhat less than yield but more than head characters. The head characters can alter the yield made possible by the number of heads per unit area, but although the differences in yield brought about by head characters are highly important in some years, the average differences caused by them are small.

The wheat plant apparently possesses a remarkable ability to undergo adjustments to various conditions that prevail throughout the season. Within rather wide limits the number of plants per unit area has very little effect on yields, for the simple reasons that the number of tillers and heads and later the number of kernels per head and weight of kernels are adjusted according to the conditions that prevail during the period of their initiation and development. As harvest approaches there is less and less opportunity for adjustment, which in turn means that those characters or characteristics that are determined latest in the season under the conditions that have prevailed at Woodward are likely to be least important in determining yields between treatments. Kernel weight, which is probably the final adjustment that can be made, played very little part in determining yields of different treatments, because the plants had already made all the growth permitted by their available moisture and plant food, and conditions severe enough to reduce kernel weight on one treatment reduced it on all others.

SUMMARY AND CONCLUSIONS

An experiment to determine the plant characters of wheat that caused differences in yield between certain crop sequences and tillage methods was conducted, holding all other factors constant within season. The plots were planted to the same variety, on the same date, at the same rate (with one exception), and with the same type of drill.

The final yield of winter wheat for the years and treatments studied was shown to be closely determined by the number of kernels per unit area. The kernel weight was never found sufficiently low to upset this foremost consideration. These results would not be expected to hold for excessive shriveling or for varieties of varying kernel size.

The number of heads per unit area as an individual indicator of yield was exceeded only by the number of kernels per unit area and the number of spikelets per unit area. Variations in number of heads per unit area were much greater than those in the number of spikelets per head and were chiefly responsible for the differences in number of spikelets per unit area.

A number of tillers sufficient to produce a large number of heads per unit area is the first requirement for a good yield. The potential number of heads per unit area is indicated from the tillering period but this may be modified by later conditions. Plants per unit area do not usually play an important part in determining number of heads per unit area because they are compensated by the number of heads per plant.

The head characters, including spikelets per head, kernels per spikelet, kernels per head, and head length, did not often vary enough to compensate for material differences in head number. In some cases, however, the yield level indicated by the number of heads and number of spikelets per unit area was considerably modified by head characters.

Conditions seldom remain favorable throughout the entire season. Drought during early growth causes an elimination of weak plants and less vigorous tillers that would otherwise produce heads. The tillers remaining are usually those which will produce heads containing an above-average number of spikelets. A greater number of spikelets per head was observed for treatments and years in which a deficiency of soil moisture was experienced.

During the heading stage some yield adjustment in favorable years is made through the number of kernels per spikelet. In comparison with the influence of head numbers on yield such adjustment is very limited. Severe conditions during the heading and flowering period, however, may in some cases cause a reduction in the number of kernels per spikelet large enough to more than compensate for differences in head numbers between treatments.

The final adjustment in yield to environmental conditions is made through kernel weight as the plant nears maturity. Significant treatment differences in this character were not apparent, indicating that hazards which reduce kernel weight on one treatment cause similar reductions on other treatments. Seasonal differences in kernel weight were apparent.

There appears to be no simple answer to the problem of character response to different methods of cultivation and crop sequence. Detailed plant descriptions at maturity demonstrate that there are many possibilities for plant characters to reflect the moisture and fertility conditions occurring at different stages of plant growth. The examination of characters pointed out that continuing adjustments of the wheat plant tend to maintain it in a condition that will enable it to take advantage of the moisture and fertility conditions then existing.

For the conditions covered by this study, the number of kernels per unit area, which is the product of the two characters number of heads per unit area and number of kernels per head, was found most practical for estimating yields. When kernel numbers were not considered, the number of heads per unit area and plant height provided the most useful estimate.

LITERATURE CITED

1. LAUDE, H. H. Relation of some plant characters to winter wheat. Jour. Amer. Soc. Agron., 30:610–615. 1938.
2. QUISENBERRY, K. S. Some plant characters determining yields in fields of winter wheat and spring wheat in 1926. Jour. Amer. Soc. Agron., 20:492–499. 1928.
3. REYNOLDSON, L. A., *et al.* The combined harvester-thresher in the Great Plains. U. S. D. A. Tech. Bul. 70. 1928.
4. SNEDECOR, GEORGE W. Statistical Methods Applied to Experiments in Agriculture and Biology. Ames, Iowa:Collegiate Press. Ed. 3. 1940.
5. SPRAGUE, H. B. Correlations and yields in bread wheats. Jour. Amer. Soc. Agron., 18:971–996. 1926.

CHEMICAL FACTORS INFLUENCING THE SET OF HENDERSON LIMA BEANS[1]

B. WOLF[2]

SOME 12,000 acres of Henderson lima beans are grown annually in the southern New Jersey area with a possible annual value of approximately $1,000,000. It has been estimated that failure of vines to form fruit or to set quite often may cause a 50% reduction in yield and considerable decrease in quality of fruit that is set. A solution or amelioration of the problem would be a great boon to both vegetable growers and packers in the region.

The failure of fruit formation or set of Henderson lima beans has long been a problem receiving considerable study. Climatic factors often have been held responsible for the failure of proper setting and undoubtedly are important. However, during the summer of 1941, vines within the same fields, in southern New Jersey subjected to the same climatic conditions varied greatly as to the number of beans set. Some vines had a good set while others but a few feet away failed to set a single bean. Vines failing to set had considerable blossoms, which would fall off to be followed by a new crop of blossoms. This process was repeated until harvest time when, quite often, such vines had failed to form any beans.

It has been a common practice to plant Henderson lima beans on well-rested soils, rich in organic matter (heavy growth of weeds). Such soils for 1 or 2 years often outyield neighboring soils devoted to continuous culture. In lieu of this fact, it was thought that chemical differences might be partly responsible for failure to set beans. It was decided to make an investigation as to differences in available nutrient content existing between well- and poorly-set plants. This paper reports the findings of the initial investigation.

METHODS AND RESULTS

PLANT TESTS

It was felt that a determination of the "available" nutrients in the plant would be the best index to the supplying power of the soil. Accordingly, Morgan's (3)[3] system of rapid soil tests for phosphorus, potassium, magnesium, and calcium and the phenoldisulfonic test for nitrates were adapted for use in this study. A photometer was used to measure accurately changes in turbidity or color (6).

Sixty-six samples of bean vines having either good or poor set were collected just prior to commercial harvesting. A preliminary study (Table 1) had shown great variation in concentration of nutrients, depending upon the portion of plant tested. As a result, it was decided to test the main and young stems. The plant samples upon being brought into the laboratory were divided into main and

[1]Contribution No. 1 from the G. L. F.-Seabrook Farms, Raw Products Research Division, Bridgeton, N. J. Received for publication March 19, 1942.

[2]Soil Chemist. The author wishes to express his appreciation to Dr. Frank App, Director of the Division, for many valuable suggestions.

[3]Figures in parenthesis refer to "Literature Cited", p. 650.

young stems and all pods shelled, recording the weight of the shelled beans. Five-gram portions of tissue, 200 ml of extracting solution, and ½ teaspoon of activated charcoal were placed in a Waring blender (2). The plant samples were reduced to a pulp by agitation for 5 minutes and then were immediately filtered, reserving the filtrate for rapid tests. At the same time 5-gram samples were taken from each portion for dry weights.

TABLE 1.—*Available nutrients in p.p.m. on a dry basis in various portions of Henderson lima bean plants.**

Tissue	Nitrate nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Main stems†	1,550	350	3,200	9,300	15,000
Young stems†	4,100	700	3,400	11,500	16,000
Petioles	4,300	300	3,400	16,800	38,000
Blades	800	700	4,500	86,000	45,000
Pods	1,100	800	9,300	6,500	10,000
Seeds	0	800	9,800	4,500	10,000

*Available in Morgan's universal extracting solution.
†Main stems were woodier portion of stem; young stems were succulent meristematic portions.

Nitrates, phosphorus, potassium, calcium, and magnesium were determined in the samples of filtrate. The average results are reported in Table 2.

TABLE 2.—*Average composition* in p.p.m. on a dry basis of Henderson lima bean plants.*

Nutrient	Tissue	Poorly-set plants	Well-set plants	Percentage of cases having more nutrient in well-set plants
Nitrate nitrogen	Main stems	950	2,250	94
	Young stems	1,050	2,200	97
Phosphorus	Main stems	700	525	29
	Young stems	1,150	875	15
Potassium	Main stems	8,500	12,400	60
	Young stems	13,800	16,500	55
Calcium	Main stems	6,100	11,200	90
	Young stems	8,300	12,500	90
Magnesium	Main stems	11,900	16,300	81
	Young stems	11,300	14,200	64

*Nutrients available in Morgan's universal extracting solution.

SOIL TESTS

Samples of soil were taken directly below each sampled plant. The samples were analyzed for nitrates and available phosphorus, potassium, calcium, and magnesium by Morgan's procedure (3). Organic matter was determined by the Schollenberger method (5). Soil pH

values were measured by a Beckman pH meter with a glass electrode in a 1:1 suspension of soil and water which had been allowed to stand for 1 hour before readings were taken.

Soil tests showed a low supply of available calcium in nearly all samples. However, samples taken directly below well-set plants had on an average a slightly higher calcium content. Approximately 85% of the soil samples below poorly-set plants, but only 50% of samples below well-set plants tested "very low" for calcium. Soil pH values, nevertheless, did not seem to have any effect upon set. This apparent contradiction can be explained by the fact that there was a poor correlation between pH and calcium content. Fifty-one per cent of the soil samples had pH values greater than 6.00; only 1% had an available calcium content greater than a "low".

Available phosphorus, potassium, or magnesium contents were not associated with set and can be considered as not limiting in this study. There was an association between organic matter content and set.

The importance of calcium and organic matter is depicted in Table 3. Calcium content of the main stems is used as an index of the supply of available calcium in the soil.

TABLE 3.—*Influence of soil organic matter and calcium content upon set and yield of Henderson lima beans.*

Soil organic matter*	Calcium content, main stems†	No. of cases	% of cases having good set	Weight of shelled beans, grams per plant
Poor	——	28	50	10
Fair	——	27	57	13
Good	——	11	78	25
	Poor	13	8	1
	Fair	21	40	6
	Good	32	92	27
Poor	Poor	5	0	0
Fair	Poor	7	14	2
Good	Poor	1	0	0
Poor	Fair	11	37	5
Fair	Fair	7	40	6
Good	Fair	3	34	20
Poor	Good	12	72	22
Fair	Good	13	100	25
Good	Good	7	100	39

*Poor = <1.5%; Fair = 1.5–2.0%; Good = 2% or more.
†Poor = <6,000 p.p.m.; Fair = 6,000–9,000 p.p.m.; Good = 9,000 p.p.m. or more.

DISCUSSION OF RESULTS

Although the number of samples analyzed is small and represents but 1 year's work, certain facts are apparent. There was a marked difference in chemical content between well- and poorly-set plants.

The concentration of nitrate nitrogen in the stems of well-set plants was higher than that of neighboring poorly-set plants. Taking the group as a whole and disregarding location, concentrations of

nitrate nitrogen in well-set plants were not always higher than in poorly-set plants.

For the entire group it appears as if concentrations of nitrate nitrogen in the main stems of less than 1,250 p.p.m. were unfavorable, although some such plants had a good set. Concentrations of 1,250 to 2,250 p.p.m. of nitrates were more favorable with 50% of the cases having a good set. All plants which contained between 2,250 to 4,000 p.p.m. of nitrates in the main stems had a good set.

Well-set plants had, as a rule, concentrations of calcium higher not only than neighboring, poorly-set plants but all poorly-set plants.

Poor, fair, and good levels of calcium in the main stems were sharply defined. In this study, plants containing less than 6,000 p.p.m. of calcium in the main stems had a poor set. If the calcium was 9,000 p.p.m. or more in the main stems, the plants usually had a good set.

Most of the poorly-set plants had higher concentrations of available phosphorus than well-set plants.

The lower concentrations of nitrate nitrogen and of calcium and the accumulation of phosphorus in poorly-set plants *may* all be a result of a calcium deficiency. Nightingale and associates (4) point to the retardation of nitrate absorption by calcium-deficient plants. In addition, the influence of calcium upon formation of nitrates in the soil is well known. Emmert (1) has reported on accumulation of available phosphorus whenever nitrates within the plant are limiting. Aside from its nitrogen-supplying power, another important function of organic matter may be in supplying calcium. In this study, soils having high organic matter contents yielded only one plant low in calcium content. It is interesting to note that limestone applications just prior to the planting of the bean crop (1941) resulted in an average increase of 300 pounds of fresh shelled beans per acre.

If the differences in seed set are markedly dependent upon a supply of available calcium in the soil, two questions arise, *viz.*, (a) Why are there differences within the same field treated with same amount of liming materials? (b) Why does not a better correlation exist between available calcium in the soil and seed set? Soil tests reveal that there is some variation in amounts of available calcium within the same field. Also, most soil samples had a rather low supply of available calcium. In such a situation it is entirely possible for individual plants to draw nutrient supplies from areas slightly different in concentration of available calcium. A small difference in the soil which is barely measurable by soil tests quite often is magnified in the plant. Such differences in concentration within the plant may mean sufficiency in one case and deficiency in another.

Organic matter had a marked influence on seed set. However, the association of calcium content of the plant with seed set was even more striking. Of great practical significance is the fact that plants having a good calcium content and grown on soil containing fair to good amounts of organic matter had a good set in all cases.

It would be advantageous to repeat this work and further studies will be made during 1942. However, results indicate that certain phases of improper seed set in Henderson lima beans may be due to chemical factors in the soil.

CONCLUSIONS

Analysis of 66 good or poorly set Henderson lima bean vines, for nitrate nitrogen, available phosphorus, potassium, calcium, and magnesium indicate that:

1. Well-set plants had substantially higher concentrations of nitrate nitrogen, potassium, available calcium, and magnesium but less available phosphorus than poorly-set plants.
2. The concentration of nitrate nitrogen and of available calcium in the main stems were closely associated with seed set.
3. The concentration of nitrate nitrogen in the stems of well-set plants was higher than that of neighboring, poorly-set plants, but not of all the poorly-set plants sampled. It was difficult to define clearly the amounts of nitrate nitrogen which were poor and fair. However, nitrate concentrations of 2,250, to 4,000 p.p.m. were associated with good set in all cases.
4. Concentrations of calcium in the main stems of well-set plants were, as a rule, higher than in poorly-set plants of the entire group. Plants having more than 9,000 p.p.m. of calcium in the main stems invariably had a good set; plants containing less than 6,000 p.p.m. had a poor set.

Results of 66 samples of soil directly beneath the sampled plants indicate:

1. A rather low supply of available calcium for all samples. However, samples taken beneath well-set plants had a slightly higher amount of calcium.
2. Soil pH values, available phosphorus, potassium, and magnesium were not limiting in this study.
3. Organic matter had a beneficial effect upon set and yield.

Combining soil and plant tests, it was shown that plants containing a good amount of calcium and grown on soil with a fair to good supply of organic matter had a good set in all cases.

LITERATURE CITED

1. EMMERT, E. M. Tests for phosphate, nitrate, and soluble nitrogen in conducting tissues of tomato and lettuce plants, as indicators of availability and yield. Ky. Agr. Exp. Sta. Circ. 43. 1934.
2. HESTER, J. B. Soil and plant tests as aids in soil fertility programs. Com. Fert. Year Book. 1941.
3. MORGAN, M. F. Soil testing methods—the universal soil testing system. Conn. Agr. Exp. Sta. Circ. 127. 1939.
4. NIGHTINGALE, G. T., ADDOMS, R. M., ROBBINS, W. R., and SCHERMERHORN, L. G. Effects of calcium deficiency on nitrate absorption and on metabolism in tomato. Plant Physiol., 6:605–631. 1931.
5. SCHOLLENBERGER, L. C. Determination of soil organic matter. Soil Sci., 31:483–486. 1931.
6. WOLF, B. Rapid plant tests by means of a photometer. (Manuscript in preparation.)

SURVIVAL OF OATS GROWN IN WINTERHARDINESS NURSERIES, 1937 TO 1941[1]

Franklin A. Coffman[2]

RESULTS from the uniform winterhardiness oat nurseries for the first 10 years, 1927 to 1936, have been published (1, 2).[3] The present paper reports data obtained in 135 of the 164 tests in which differential killing occurred in the five years since 1936.

These experiments were conducted as in previous years, except that two rows of each variety or strain were seeded, 50 seeds per row, instead of 100 seeds in a single row. Also, they include a somewhat larger proportion of new varieties and hybrids. Table 1 gives the location of each nursery, the number of years grown, and the names of the cooperators. The general area represented by these nurseries is about the same as for the earlier tests, except for the addition of several stations in the Pacific Northwest.

Winterkilling was not unusually severe in any of the five seasons. Temperatures during the winter of 1939–40 were exceptionally low, but survival was about average, due probably to snow covering much of the winter oat area during the low temperature period. Averages only are given in the present report. It is possible, as suggested earlier (2), that varieties may respond differently at different stations; but, if so, more critical studies, or studies for a longer period than those reported herein, will be necessary to prove it.

EXPERIMENTAL RESULTS

A total of 58 varieties and selections was tested during the period. The average survival of the varieties grown in all tests in which differential killing was recorded is listed by years in Table 2. Of the 58 varieties, 24 ordinarily are classified on a morphological basis as belonging to *Avena sativa* and 34 to *A. byzantina*. Varieties classed as *A. sativa* are subdivided into the groups Black Winter, Culberson, Lee, and Winter Turf. Those classified as *A. byzantina* are subdivided into Fulghum, Red Rustproof, and miscellaneous strains. The latter group includes a few varieties believed to be heterozygous.

It will be noted that 10 of the *Avena sativa* and 10 of the *A. byzantina* varieties or strains appear to be as hardy as or more hardy than Winter Turf (C. I. 3296),[4] here used as the standard of comparison, during the entire period that they were tested.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication March 23, 1942.

[2]Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Acknowledgement is hereby made to T. R. Stanton for assistance in selecting the varieties tested, to S. C. Salmon and J. H. Martin for assistance in preparing the presentation of the data, and to all the cooperators listed in Table 1 who prepared data on the hardiness nurseries grown on their respective stations.

[3]Numbers in parenthesis refer to "Literature Cited", p. 658.

[4]C. I. number refers to accession number of the Division of Cereal Crops and Diseases.

TABLE 1.—*Stations at which winterhardiness nurseries were grown from 1937 to 1941 and names of cooperators.*

Locations		Cooperators*	No. of years grown
State	Place		
New Jersey	New Brunswick	H. B. Sprague, C. S. Garrison	5
Maryland	College Park	R. G. Rothgeb	1
	Beltsville	J. W. Taylor, Wm. S. Becker	1
Virginia	Arlington	J. W. Taylor, Horace Garth, Wm. S. Becker	5
	Blacksburg	M. S. Kipps	2
	Glade Spring	C. W. Ryburn, W. R. Perkins	5
West Virginia	Kearneysville	R. O. Weibel, J. W. Taylor	1
North Carolina	Statesville	G. K. Middleton, J. W. Hendricks, W. H. Chapman	5
	Swannanoa	G. K. Middleton, S. C. Clapp	4
South Carolina	Clemson	G. B. Killinger, H. P. Cooper	4
	Hartsville	Geo. J. Wilds, R. S. Cathcart	5
	Westminster	S. J. Hadden	1
Georgia	Experiment	R. P. Bledsoe, Laurence N. Skold, S. J. Hadden	5
	Tifton	H. S. Garrison	5
Florida	Quincy	J. D. Warner	4
Tennessee	Knoxville	N. I. Hancock, H. P. Ogden	5
Alabama	Fairhope	Harold F. Yates	5
Mississippi	State College	J. Fred O'Kelly, A. D. Suttle	4
	Stoneville	P. W. Gull, H. A. York	5
	Westpoint	T. F. Akers	5
Iowa	Ames	H. C. Murphy	1
Missouri	Columbia	J. M. Poehlman, B. M. King	4
	Sikeston	J. M. Poehlman, Carl O. Luper, B. M. King	5
Arkansas	Fayetteville	C. K. McClelland	5
	Stuttgart	C. Roy Adair	5
Louisiana	Baton Rouge	John P. Gray, Dawson M. Johns	3
	Calhoun	Sidney Stewart, John P. Gray	3
	St. Joseph	Dawson M. Johns, John P. Gray, C. B. Hadden	3
Oklahoma	Stillwater	C. B. Cross	2
	Lawton	L. W. Osborn, R. G. Dahms	5
	Lone Grove	G. W. Statton, C. B. Cross	2
	Woodward	V. C. Hubbard	4

*Persons transmitting data to U. S. Dept. of Agriculture. Cooperator in 1941 is listed first; the others follow.

TABLE 1.—*Concluded.*

Locations		Cooperators*	No. of years grown
State	Place		
Texas	Denton	I. M. Atkins	5
	Amarillo	David A. Reed, I. M. Atkins	3
	Bushland	David A. Reed	1
	Greenville	D. R. Hooten, H. C. McNamara	5
	Temple	H. O. Hill, C. H. McDowell, H. E. Rea	5
	College Station	E. S. McFadden, P. C. Mangelsdorf	5
Washington	Pullman	O. E. Barbee	3
	Puyallup	M. S. Grunder, O. E. Barbee	4
	Battle Ground	W. Perry, O. E. Barbee	3
	Mt. Vernon	H. E. Harndon, O. E. Barbee	3
Oregon	Astoria	H. B. Howell, Roderick Sprague	4
	Corvallis	D. D. Hill	4
Total			164

*Persons transmitting data to U. S. Dept. of Agriculture. Cooperator in 1941 is listed first; the others follow.

Among the more hardy varieties of the *sativa* type are Tech, Hairy Culberson, Wintok (Hairy Culberson×Fulghum, Okla. Sel. 1-32-1446, C. I. 3424), Bicknell, Letoria, and Stanton. The latter was grown only in 1941. Although all exceeded the Winter Turf check in average survival, few of them have been tested for long periods and the margin of superiority was slight in every case.

Among *Avena byzantina* strains, 8 of 15 in the Fulghum group survived better than Winter Turf, during the entire period that were tested, and of these 6 were grown in more than 75 tests. Probably Fulwin and Tennex, reselections from Fulghum (winter type) (C. I. 2499), made at the Tennessee Agricultural Experiment Station (10), are most hardy. As a group, the Red Rustproof type oats had the poorest average survival. Unusually cold weather early in November 1940 seriously reduced stands of all winter oats but seemed particularly injurious to the Red Rustproof strains. None of the Red Rustproof type oats approaches Winter Turf in average survival for all tests. Appler, considered a typical Red Rustproof strain, has survived 91.3% as well as Winter Turf. Data obtained indicate no particular difficulty has been met in obtaining selections from Red Rustproof crosses which equal Appler in hardiness.

Among the "miscellaneous" strains, one selection from the cross Markton×Red Rustproof (C. I. 3430) exceeded Winter Turf in hardiness.

Fulghum (C. I. 708), which appeared to be the least hardy of any variety grown throughout the 10-year period previously reported (2), exceeded Winter Turf in hardiness in the tests reported herein. This is attributed to the action of natural selection during the earlier period. The Fulghum seed used in these tests has been saved from

TABLE 2.—*Summarized annual percentage survivals of winter oat varieties and average survivals compared with that of the Winter Turf variety.*

Varietal type and variety or selection	C. I. No.	1937 (22 stations)	1938 (31 stations)	1939 (24 stations)	1940 (29 stations)	1941 (29 stations)	Weighted average survival: Variety	Weighted average survival: Winter Turf (same tests)	Percentage of Winter Turf: 1937–1941	Percentage of Winter Turf: 1926–1941	Number of tests: 1937–1941	Number of tests: 1926–1941
Avena sativa												
Black Winter:												
Tech	947	86.1	68.1	76.6	73.4	61.9	72.4	71.4	101.4	100.0	135	273
Culberson:												
Hairy Culberson	2505	88.1	71.3	77.2	75.3	64.8*	74.6*	71.2*	104.8	105.4	134*	272*
Bicknell	3218	83.4	70.9	82.5	72.9	63.2	73.8	71.4	103.4	104.7	135	273
Wintok	3424	—	75.1	78.7	77.6	67.2*	74.5*	68.8*	108.1	—	112*	—
Hairy Culberson × Victoria	3414	—	—	74.1	69.7	—	71.7	75.7	94.7	—	53	—
Hairy Culberson × Fulghum (winter type) C. I. 2500	3524	—	—	78.5	—	—	78.5	79.9	98.2	—	24	—
Hairy Culberson × Victoria	3413	—	62.6	—	—	—	62.6	67.6	92.6	—	31	—
Lee:												
Lee	2042	83.8	62.0	76.4	70.2	54.9	68.3	71.4	95.7	97.1	135	273
Letoria	3392	—	—	81.1	74.7	65.5	73.3	69.6	105.3	—	82	—
Stanton (Coker)	3855	—	—	—	—	64.0	64.0	58.5	109.4	—	29	—
Lee × Victoria	3694	—	—	—	64.2	61.9	63.1	65.4	96.5	—	58	—
Lee × Bond	3695	—	—	—	64.2	57.7	61.0	65.4	93.3	—	58	—
Lee × Fulghum (winter type) C.I. 2500	3696	—	—	—	68.1	62.2	65.2	65.4	99.7	—	58	—
Lee × Fulghum (winter type) C.I. 2500	3425	—	69.0	75.8	66.1	—	69.9	72.7	96.1	—	84	—
Lenoir	3393	—	—	79.3	69.6	—	74.0	75.7	97.8	—	53	—
Lee × Victoria	3433	—	60.5	74.5	—	—	66.6	73.0	91.2	—	55	—
Lee × Victoria	3380	—	57.4	—	—	—	57.4	67.6	84.9	—	31	—
Lee × Victoria	3398	—	57.6	—	—	—	57.6	67.6	85.2	—	31	—
Winter Turf:												
Winter Turf	3296	83.5	67.6	79.9	72.2	58.5	71.4	71.4	100.0	100.0	135	273
Pioneer	3427	—	70.2	77.2	73.0	64.9	71.0	69.1	102.7	—	113	—
(Winter Turf × Aurora) × Culred	3426	—	72.6	75.9	—	—	74.0	73.0	101.4	—	55	—
Support	3180	87.7	67.3	—	—	—	75.8	74.2	102.2	—	53	—
Spören	2506	87.7	—	—	—	—	87.7	83.5	105.0	103.8	22	139
Winter Turf (Indiana strain)	3252	85.4	—	—	—	—	85.4	83.5	102.3	—	22	—

Avena byzantina													
Fulghum:													
Fulghum	708	88.0	70.0	77.4	70.9	65.7	73.5	71.4	102.9	96.6	135	273
Fulghum (winter type)	2498	85.0	67.6	80.5	65.2	64.4	71.5	71.4	100.1	100.7	135	268
Fulghum (winter type)	2499	85.7	71.4	77.0	72.3	66.6	73.9	71.4	103.5	104.1	135	273
Fulwin	3168	91.2	76.1	80.2	74.5	70.9	77.8	71.4	108.9	—	135	—
Tennex	3169	90.1	75.6	83.0	73.5	68.8	77.4	71.4	108.4	—	135	—
Fultex	3531	—	—	—	66.7	59.1	62.9	65.4	96.2	—	58	—
Victorgrain	3692	—	—	—	58.7	57.5	58.1	65.4	88.8	—	58	—
Fulgrain Strain 4	3693	—	—	—	59.3	57.1	58.2	65.4	89.0	—	58	—
Fulghum × Victoria (Arlington Selection 1071)	3747	—	—	—	—	59.3	59.3	58.5	101.4	—	29	—
Fulgrain	3253	83.6	62.7	75.0	—	—	72.5	76.0	95.4	—	77	—
Fulghum (winter type, Tennessee Selection 090)	3175	86.1	72.6	78.4	—	—	78.3	76.0	103.0	105.2	77	118
Coker's Selection 32–1	3026	85.2	70.1	—	—	—	76.4	74.2	103.0	102.9	53	108
Fulgrain Strain 3 (Coker's)	3423	—	59.8	—	—	—	59.8	67.6	88.5	—	31	—
Forkadeer	3170	89.2	—	—	—	—	89.2	83.5	106.8	—	22	—
Coker's Selection 33–47	3176	87.7	—	—	—	—	87.7	83.5	105.0	96.5	22	64
Red Rustproof:												
Appler	1815	74.4	58.4	70.3	59.5	53.7	62.3	71.4	87.3	91.3	135	273
New Nortex	3422	77.6	62.1	71.8	61.9	58.4	65.5	71.4	91.7	—	135	—
Nortex × Victoria	3535	—	—	—	58.9	51.2	55.1	65.4	84.3	—	58	—
Ranger	3417	—	—	65.8	—	51.2	57.7	68.2	84.6	—	53	—
Rustler	3754	—	—	—	—	53.8	53.8	58.5	92.0	—	29	—
Rangler	3733	—	—	—	—	54.5	54.5	58.5	93.2	—	29	—
Red Rustproof[2] † × (Victoria × Richland)	3725	—	—	—	—	52.1	52.1	58.5	89.1	—	29	—
Nortex × Victoria	3525	—	—	46.3‡	52.9	—	51.8	71.3‖	72.7‖	—	35	—
Nortex × Victoria	3526	—	—	82.9§	54.7	—	64.3	77.6‖	82.9‖	—	44	—
Red Rustproof × Winter Turf	3523	—	—	73.9	—	—	73.9	79.9	92.5	—	24	—
Nortex	2382	73.1	57.1	—	—	—	63.7	74.2	85.8	90.6	53	185
Ferguson No. 922	2150	84.1	—	—	—	—	84.1	83.5	100.7	89.2	22	155
Alber	2766	61.4	—	—	—	—	61.4	83.5	73.5	65.3	22	100
Miscellaneous strains:												
Markton × Red Rustproof	3179	82.6	66.7	82.0	64.3	60.1	70.1	71.4	98.2	97.4	135	173
Markton × Red Rustproof	3430	87.0	73.7	81.0	67.3	63.3	73.6	71.4	103.1	—	135	—
Woodward composite	3527	—	—	79.1	74.9	—	76.8	75.7	101.5	—	53	—
Fulghum (winter type) C.I. 2500 × Winter Turf	3431	85.0	71.1	72.7	—	—	75.6	76.0	99.5	—	77	—
Fulghum (winter type) C.I. 2500 × Custis	3432	82.1	64.5	—	—	—	71.8	74.2	96.8	—	53	—
Fulghum (winter type) C.I. 2500 × Custis	3433	71.9	—	—	—	—	71.9	83.5	86.1	—	22	—

*Destroyed by soil washing at Fayetteville, Ark., in 1941.
†Backcrossed to Red Rustproof twice.
‡Data are available from only six nurseries in 1939 wherein this selection's survival average equalled only 69.3% of Winter Turf.
§Data are available from only 15 nurseries in 1939 wherein this selection's survival average equalled only 94.3% of Winter Turf.
‖Percentages are for fully comparable data only.

year to year at Arlington Experiment Farm so that in later tests progeny of the same strain as that grown in earlier tests was studied. The variable nature of Fulghum, including the C. I. 708 strain, has long been known (8, 9). Only a few plants of this variety survived the severe season of 1934 and it appears probable that the progeny of these are more hardy than the original variety.

DISCUSSION

The data presented, considered in conjunction with those presented earlier, indicate that progress has been made in breeding hardier varieties, but more particularly in combining the hardiness of the most winter hardy varieties with other desirable agronomic characteristics. Winter Turf, long considered our most hardy variety, has been shown to be less hardy than Hairy Culberson. Though hardy, neither of these has been widely grown because both lacked yielding ability.

Data presented herein indicate that Fulwin and Tennex are slightly more hardy than Hairy Culberson, and moreover they are valuable, high-yielding varieties which produce grain of acceptable quality and have been distributed to farmers in Tennessee and elsewhere. Wintok has been distributed in Oklahoma. In comparisons involving more than 100 station years, all three of these new strains have exceeded Winter Turf in average survival percentages by more than 8%. In addition to their hardiness, all give promise of becoming valuable agronomic varieties. They seem equal to or better than Hairy Culberson in hardiness, and already have proved valuable on farms because of their high yields of good quality grain.

Fultex (C. I. 3531), which resulted from crossing Victoria and Fulghum, has proved moderately hardy. It is smut and crown rust resistant, has stiff straw, and has been a high-yielding variety in Texas (6) and elsewhere. Two new varieties, Ranger and Rustler, have been produced from the cross Nortex×Victoria (3, 11). Apparently they yield as well as Nortex and approach Nortex in hardiness, and in addition have crown rust and smut resistance. They have been released for commercial production in Texas.

One selection (C. I. 3725) is resistant to crown rust, stem rust, and smut and apparently approaches its Red Rustproof type parent in hardiness (3) thus indicating the possibility or probability of obtaining hardy varieties resistant to these major oat diseases.

In these crosses it has not been difficult to recover the winterhardiness of the more hardy parent. In some cases, such as Wintok, Letoria, Pioneer, and Markton×Red Rustproof (C. I. 3430), the average survival is slightly in excess of that of the more hardy parent.

It is significant that all of the more hardy oats in these nurseries which were evolved by selection were selected from varieties orginating from the red oat group, yet all have certain characters resembling *Avena sativa*. Among these are Fulwin, Tennex, and Hairy Culberson.

In previous papers (1, 2), the possibility of obtaining increased hardiness in oats by species hybridization was mentioned. This idea

would seem to be further substantiated by the fact that the four more hardy hybrid strains mentioned in the present paper and listed below resulted from interspecies crosses involving *Avena sativa* and *A. byzantina*. Wintok resulted from crossing Hairy Culberson with Fulghum, Letoria from the cross Lee×Victoria (6, 7), Pioneer from crossing a segregate of the cross Winter Turf×Aurora with Fulghum, and C. I. 3430 from crossing Markton with Red Rustproof. Although these four varieties all presumably resulted from so-called species crosses, both immediate parents in every case, unless it be the Markton variety, include in their ancestry varieties of red oats, presumably derivatives of the wild red oat *A. sterilis* L.

Markton, usually classed as belonging to *Avena sativa*, was derived from oats introduced from Turkey, and its geographical origin, as well as some of its characteristics, suggest the probability of some red oat in its ancestry (4, 5).

The only hardy oats grown from fall seeding in the United States whose ancestry has not been traced at least in part to the supposed derivatives of *Avena sterilis* are those of the Winter Turf group. Their origin either in Europe or America is obscure, but in plant and kernel characters they are so like oats of the Culberson group which trace their origin to red oats that the origin of the two groups could well have been similar.

Consequently, although species hybridization would seem to be the most promising method for producing hardier oats, it would appear most of the genes for cold resistance may be found among the red oats. This suggests that the red oat group might well be explored more thoroughly in the search for varieties to be used in crossing to produce increased winterhardiness.

SUMMARY

Five years' additional data from the uniform winterhardiness oat nurseries substantiate, in most cases, the results of the 10 previous years, already published. Hairy Culberson is the most hardy oat grown during the entire period of 15 years, but several new varieties, including Tennex, Fulwin, and Wintok, are as hardy as or slightly more hardy than Hairy Culberson. These three are high-yielding varieties with much promise, whereas Hairy Culberson is relatively unproductive.

Several new varieties, *viz.*, Letoria, Ranger, Rustler, and Fultex, resulting from crosses of Victoria with Lee, Nortex, or Fulghum, combine the crown rust and smut resistance of Victoria with the hardiness of their other parents. Seed of most of these new varieties has been increased and distributed to farmers.

One selection, C. I. 3725, is resistant to crown rust, stem rust, and smut and appears to be about equal to its Red Rustproof parent in winterhardiness. It appears, therefore, that the breeding of hardy varieties having resistance to all these diseases should be possible.

Whereas the production of disease-resistant oats even more hardy than Hairy Culberson now seems assured, it still will be necessary to obtain even greater hardiness if the growing of winter oats is to be extended much northward.

As evidence exists for believing all more winter hardy oats grown in America include in their ancestry certain red oat strains, it would appear advisable to investigate most thoroughly the red oats as a probable source for additional new genes for winterhardiness.

LITERATURE CITED

1. COFFMAN, F. A. Species hybridization, a probable method for producing hardier winter oats. Jour. Amer. Soc. Agron., 29:79–81. 1937.
2. ———. The comparative winter hardiness of oat varieties. U. S. D. A. Circ. 622. 1941.
3. ———, HUMPHREY, H. B., and MURPHY, H. C. New red oats for fall seeding resistant to rusts and smuts. Jour. Amer. Soc. Agron., 33:872–882. 1941.
4. ———, and STANTON, T. R. Variability in germination of freshly harvested Avena. Jour. Agr. Res., 57:57–72. 1938.
5. ———, and STEVENS, HARLAND. Influence of certain oat varieties on their F_1 progeny. Jour. Amer. Soc. Agron., 29:314–323. 1937.
6. MURPHY, H. C., STANTON, T. R., and COFFMAN, F. A. Breeding for disease resistance in oats. Jour. Amer. Soc. Agron., 34:72–89. 1942.
7. ———, STANTON, T. R., and STEVENS, HARLAND. Breeding winter oats resistant to crown rust, smut, and cold. Jour. Amer. Soc. Agron., 18:622–637. 1937.
8. SALMON, S. C., and PARKER, JOHN H. Kanota: An early oat for Kansas. Kans. Agr. Exp. Sta. Circ. 91. 1921.
9. STADLER, L. J., and KIRKPATRICK, R. T. Columbia oats, a new variety for Missouri. Mo. Agr. Exp. Sta. Bul. 278. 1930.
10. STANTON, T. R. Registration of varieties and strains of oats, IX. Jour. Amer. Soc. Agron., 32:76–82. 1940.
11. ———. Registration of varieties and strains of oats, X. Jour. Amer. Soc. Agron., 33:246–251. 1941.

LINKAGE RELATIONSHIPS BETWEEN THE ALLELOMORPHIC SERIES B, B^{mb}, B^{g}, AND A_ta_t FACTORS IN BARLEY[1]

R. W. WOODWARD[2]

IT has previously been shown[3] that possibly three or more color intensity classes for the melaninlike pigment found in the glumes and caryopses of barley form an allelomorphic series. Robertson[4] has shown that the A_ta_t factor pair for normal vs. albinos in Trebi I are linked with the black vs. white gene pair, giving 22.3% recombinations. Each color group should then show similar linkage with the albino factor. Few genes have been located in group 2, giving little choice of suitable material for crosses. The character known as third outer glume, found by Ivanova to be linked with the black vs. white pair, cannot be obtained. The albino factor found in Trebi I appears to be the only suitable factor for making linkage studies with the black and white factor pair.

Trebi I was used in crosses with representative varieties of the four black color classes previously reported by the author.[5] Several plants of the Trebi I parent were used in each cross to insure locating the A_ta_t type which is indistinguishable from the homozygous normal A_tA_t type.

C. I. 708 was used to represent the dense black; Jet (C. I. 2222) for the black group; C. I. 2970 for the medium black; and C. I. 875, a light segregate, for the gray. A study was made of the F_2 breeding behavior of these crosses. Approximately 25% of the F_2 plants were lethal albinos in crosses involving the A_ta_t factor pair, while the families with the A_tA_t factor pair appeared normal. In crosses of the Bb and A_ta_t type, two of the 9:3:3:1 groups, namely, the Ba_t and ba_t phonotypes, were seedling lethals. With no linkage, ratios of 3 black to 1 white would be the expected from the BA_t and bA_t classes in the F_2 generation.

Individual family segregations for each of the four colored classes $\times$Trebi I in which the A_ta_t type is concerned are presented in Table 1.

Linkage relationships and the percentage of recombinations were

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Utah Agricultural Experiment Station, cooperating. Approved for publication by the director of the Utah Agricultural Experiment Station, November 26, 1941. Received for publication March 23, 1942.

[2]Assistant agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The author wishes to express his appreciation to H. V. Harlan for the black barleys, to D. W. Robertson for the Trebi I used in these studies, and to F. R. Immer for suggestions and help in analyzing the data.

[3]WOODWARD, R. W. Inheritance of a melaninlike pigment in the glumes and caryopses of barley. Jour. Agr. Res., 63:21–28. 1941.

[4]ROBERTSON, D. W. Linkage studies in barley. Genetics, 14:136. 1929.

[5]*Loc. cit.*

TABLE 1.—*F_2 results from crosses of Trebi I A_ta_t × representatives of four classes for the melaninlike pigment in barley glumes.*

Family	Segregation (observed)		Calculated with 36.7% recombinations	Actual
	Black	White	White	C. O., %
Class I, Dense Black (BB) × Trebi I (A_ta_t)				
1	679	167	170	36.1
2	588	128	144	31.9
3	309	82	79	39.1
4	313	73	78	34.2
5	487	115	121	34.7 $X^2=2.56$
Total	2,376	565	591 $X^2=1.14$ C.O. = 35%	
Class II, Black (BB) × Trebi I (A_ta_t)				
1	281	69	70	36.1
2	348	94	89	39.8
3	588	159	150	39.9 $X^2=0.854$
Total	1,217	322	309 $X^2=0.55$ C.O. = 38.9%	
Class III, Medium Black ($B^{mb}B^{mb}$) × Trebi I (A_ta_t)				
1	202	56	52	40.9
2	198	41	48	30.3
3	139	37	35	39.2 $X^2=1.44$
Total	539	134	135 $X^2=0.00$ C.O. = 36.6%	
Class IV, Gray (B^gB^g) × Trebi I (A_ta_t)				
1	293	84	76	42.3
2	206	52	52	37.1
3	204	51	51	36.8 $X^2=0.8$
Total	703	187	179 $X^2=0.36$ C.O. = 39.2%	

derived by the formula $P^2=\frac{\text{Black}-2\ (\text{White})}{\text{Total}}$. All the crosses were made in the coupling phase. Counts were made of all families whether segregating for albinos or not, and the individual data are shown.

As was explained previously, some of the families lacked the (a_t) factor and gave normal segregations as shown in Table 2 by the representative families from each of the color class crosses × Trebi I. The results indicate no linkage for the normal families, but show the characteristic excess of white over black found at this station.

TABLE 2.—*Normal F_2 families for each black color class × homozygous Trebi I, (A_tA_t).*

Class	Number of families	Segregation (observed)		Calculated 3:1	
		Black	White	White	X^2
A_tA_t ×					
(1) Dense Black (BB)	4	796	297	273	3.587
(2) Black (BB)	3	759	271	258	0.9
(3) Medium Black ($B^{mb}B^{mb}$)	2	577	205	196	0.413
(4) Gray (B^gB^g)	3	711	260	243	1.189

The entire group of families producing albinos was combined and the percentage recombinations calculated.

There were 4,835 black to 1,208 white plants. The expectation on the basis of a 3:1 segregation was 1,511 white. X^2 in this case is 80. On the basis of 36.7% recombinations, the calculated number of white is 1,214 which gives a X^2 of 0.017, which is well within the limits of expectation for the data obtained.

A homogeneity test was made in which the totals of the four black F_2 groups×Trebi I gave a X^2 of 8.155 which is below the 5% point of 9.5, indicating homogeneity. It is recognized that phenotypic ratios from two classes may not be as reliable as from a back cross or from F_2 genotypes where equal populations are used.

However, in this investigation, four separate crosses, representing the four black allelomorphic color classes previously described[6] were made up of 14 families and over 6,000 F_2 plants. The crossover values for individual families ranged from 30.3 to 42.3 for the four different crosses from 35.0 to 39.2, with a grand average of 36.7%.

The results of this study favor the theory that these black classes form an allelomorphic series as was pointed out earlier with a crossover value near 36.7%.

[6]See footnote 3.

EARLINESS OF MATURITY AS A FACTOR INFLUENCING SEED PRODUCTION IN VETCH[1]

H. R. ALBRECHT[2]

PROBABLY no single factor has impeded the progress of the winter legume program in Alabama more than the inability of the most commonly grown variety, hairy vetch (*Vicia villosa* L.), to produce seed in abundance in the state. Other vetches, such as Hungarian (*V. pannonica* Crantz.) and common (*V. sativa* L.), are also unsatisfactory and uncertain seed producers in Alabama.

Certain cultural methods can be applied when vetch is planted for seed production which lead to more certain and usually to greater seed yields (1).[3] These include reduced rates of seeding, support of vines by small grains or, preferably, by dead cotton stalks, application of sufficient quantities of phosphorus, potassium, and lime, and timely harvests.

No strains of hairy or of Hungarian vetch which are significantly more prolific than the commercial strains available have been developed by the Alabama Agricultural Experiment Station. Some high seed-producing strains of common vetch have been developed, but most progress has been made with woollypod vetch (*V. dasycarpa* Ten.) and monantha vetch (V. *monantha* (L.) Desf.). It is believed that highly prolific varieties of vetch suitable for use in Alabama can be developed only in those species which are normally early in maturity or which lend themselves to selection of early maturing strains.

METHODS

Each fall during the period of 1936–40, inclusive, new vetch introductions and selections were planted in 50-foot rows spaced 4 feet apart. Two or three rows were planted whenever seed stocks permitted. All rows were thinned when the plants were in the seeding stage to assure a uniform stand in each row.

The date of first bloom, full bloom, and harvest of seed of each vetch strain was recorded each year. Any one of these can be considered as a criterion of maturity in the vetches. Early maturing strains were selected at one or all stages of development.

Thus far, selection has been the only plant breeding technic employed with success in the Alabama vetch-improvement program. All efforts to produce hybrids in the vetches have failed, but sufficient variation appears to exist in the various species of the genus *Vicia* to make selection a valuable method in the improvement of vetches.

The vetches were harvested upon maturity and the seed was threshed and weighed. The strains were classified according to their date of maturity as either early, intermediate, or late. The early vetches were usually harvested late in May, the intermediate early in June, and the late vetches in mid-June or late in June.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication April 13, 1942.

[2]Assistant Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 666.

DISCUSSION AND RESULTS

When the Alabama vetch-improvement program was begun in 1936, two particular failings of the commonly grown vetches were recognized as limiting the use of vetches as a soil improvement crop in Alabama. The poor seed yields of vetches in Alabama, necessitating substantial expenditures of money annually for seed produced outside the State, have already been mentioned. In addition, vetches occasionally do not produce adequate growth early enough to fulfill their primary purpose, that of soil conservation and improvement.

The relation of earliness of maturity to greater seed yields of the vetches grown at Auburn during the years 1936–40 is shown in Table 1. The early maturing strains, on the average, exceeded those of intermediate and late maturity in quantities of seed produced and the late strains yielded less seed than did the strains of intermediate maturity. The value of "r" has been calculated for each year's data and substantiates the thesis that earliness of maturity is closely related to high seed production in the vetches.

TABLE 1.—*Relation of date of maturity to seed production of vetch.*

Year	Maturity						r
	Early		Intermediate		Late		
	Number of families	Lbs. of seed produced, av.*	Number of families	Lbs. of seed produced, av.*	Number of families	Lbs. of seed produced, av.*	
1936	11	0.57	23	0.42	16	0.28	−0.313±0.089
1937	13	0.56	25	0.48	12	0.13	−0.577±0.074
1938†	17	0.70	20	0.11	14	0.04	−0.729±0.044
1939	14	0.49	40	0.31	32	0.15	−0.583±0.049
1940†	93	0.90	370	0.04	165	0.00	−0.503±0.024

*Seed harvested from 50-foot row.
†Intermediate and late strains severely attacked by corn earworms and aphids.

The values of "r" calculated from the data of 1936 through 1940 are in every instance significant, according to Snedecor's (3) table of "r". The values determined in the years 1937 through 1940 are highly significant due to the fact that many of the vetches tested in these years were progenies of plants that had been selected for their earliness of maturity. The vetches grown in 1936 were largely introductions of undetermined maturity.

Most of the 103 monantha vetch strains planted in the fall of 1940 were progenies of plants selected in June 1940 in farmers' fields. Selection was based on number of pods per plant and size of plant. Nevertheless, all but 4 of the 93 strains classified as being early in maturity in 1940 (Table 1) came out of this group of vetch strains. The monantha vetch strains were reclassified according to date of maturity and 12 were found to have matured early in May (average

seed yield, 1.21 pounds), 24 in mid-May (average seed yield, 0.95 pound), and 67 late in May or early in June (average seed yield, 0.82 pound). Here again, in this early maturing species, the earliest strains yielded the greatest quantities of seed on the average, and the least quantities were produced by the late-maturing strains. The value of "r" was calculated to be 0.211 ± 0.063.

It is not contended that vetches of intermediate or late maturity always fail to produce satisfactory yields of seed in Alabama. They are, however, subject to severe insect attacks that frequently occur in late spring and cause substantial reductions in seed production of vetch. The insects which often cause severe injury to vetch that is to be harvested for seed include (1) the corn earworm (*Heliothis obsoleta* F.), the pea aphid (*Illinoia pisi* Kalt), and the tarnished plant bugs (*Lygus* sp.). Observations made in the field suggest that the high temperatures and humidity which are often prevalent during the flowering period of the late-maturing vetches also cause some reductions in seed yields. Blossom drop has been noted to be far more common when such adverse weather conditions prevail.

It is fortunate that the most promising early maturing species of vetch, monantha, tested at Auburn is highly resistant to shatter. As a result, harvests of this vetch can be delayed until the entire seed crop is matured. All other vetches shatter their seed severely, particularly when rains cause continued delays of harvest.

In trials at Auburn, Prattville, and Alexandria, monantha vetch

TABLE 2.—*Seed yields of vetch in Alabama, pounds per acre.*

Variety	Auburn, 10-yr. av.	Prattville, 5-yr. av.	Alexandria, 4-yr. av.
Hairy	79	252	157
Hungarian	69	154	600
Monantha	178	269	1,064
Common*	28	172	494
Willamette	73	248	225

*2 years in test, 1936–37.

TABLE 3.—*Green weight yields of vetch varieties tested in three general sections of Alabama, 1926–1940.*

Variety	Green weight, av. pounds per acre			
	North*	Central†	South‡	State
Hairy	7,842	7,388	7,463	7,527
Hungarian	6,008	3,766	3,736	4,366
Monantha	8,840	7,590	9,383	8,500
Oregon Common§	9,257	6,395	6,161	7,271
Willamette	8,204	6,927	6,049	6,956
Alba‖	6,969	4,866	6,698	5,974

*Tennessee Valley and Sand Mountain Substations and Alexandria Experiment Field.
†Auburn, Black Belt Substation, and LaFayette, Prattville, and Aliceville Experiment Fields.
‡Wiregrass and Gulf Coast Substations and Brewton and Monroeville Fields.
§1934 and 1935 averages only.
‖1935 and 1936 averages only.

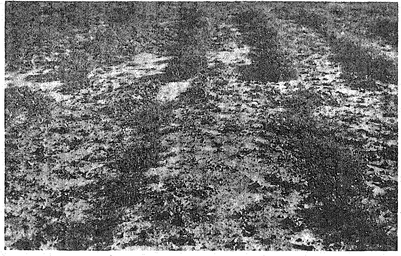


FIG. 1.—Foreground, hairy vetch; to rear, Monala, an early maturing variety which is capable of heavy growth late in winter and early in spring. Photographed March 10, 1942.

has consistently outyielded all other varieties and species of vetch tested in pounds of seed produced (Table 2). It has also proved to be the most productive green manure crop in all sections of the state in which it has been tested. (Table 3). Failures of monantha vetch due

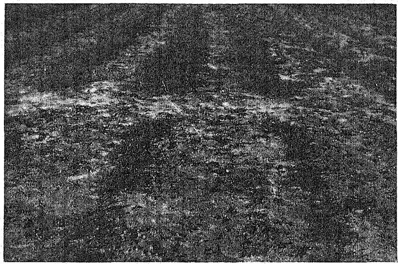


FIG. 2.—Foreground, hairy vetch; to rear, Auburn Woollypod. Spring growth, photographed March 10, 1942.

to injury by cold have been recorded in the tests, but none has been experienced since 1936 when the LaFayette strain was substituted for commercial monantha vetch in all trials.

The LaFayette and Monala varieties of monantha vetch are amply hardy for use in all sections of Alabama and usually produce sufficient vegetative growth to permit early turning of the crop for green manure purposes. They are highly susceptible to root rot, however, and therefore should not be planted on poorly drained lands.

Selection for earliness in the vetches is usually accompanied by a reduction in vegetative vigor. This is particularly true in the instance of the common vetches where all early maturing, more prolific strains now at hand are relatively short stemmed and sparsely vegetative. A number of monantha and a few woollypod vetch selections are notable exceptions (Figs. 1 and 2). These promising strains are not only capable of producing ample quantities of seed and green matter, but they also produce relatively large amounts of vegetation during the winter when other vetches are more or less dormant.

Common vetch, including the varieties Willamette and Alba, and Hungarian vetch are not generally satisfactory green manure crops on the more unproductive lands of Alabama. Only hairy vetch or woollypod vetch (2) should be planted on lands of low fertility or on highly eroded areas.

SUMMARY

Studies of dates of maturity and seeding ability of many strains of several species of *Vicia* reveal that early maturing vetches are generally the best seed producers.

The most promising strains of vetch developed by the Alabama Agricultural Experiment Station to date have been selected out of monantha vetch (*V. monantha* (L.) Desf.). They are heavy producers of seed and are capable of vigorous early spring growth, permitting early turning when the vetch is to be used as a green manure crop. The LaFayette and Monala varieties of monantha vetch are amply hardy for use in all sections of Alabama. A few early maturing strains of woollypod vetch (*V. dasycarpa* Ten.) are also highly satisfactory seed producers, but, unlike the monantha vetch varieties, they shatter their seed heavily as the pods mature.

The early maturing varieties of vetch apparently are more prolific than the later maturing vetches, notably hairy vetch (*V. villosa* L.). The early vetches are past their flowering period and at least the major portion of their seed crop has been matured before adverse weather conditions, such as high temperatures and humidity, prevail. Their earliness also makes it possible to escape the severe late spring insect devastations which occur so commonly in Alabama. The seed crops of late-maturing vetches in Alabama are often substantially reduced or even completely destroyed by attack by certain insects, particularly the pea aphid (*Illinoia pisi* Kalt.) and the corn earworm (*Heliothis obsoleta* F.).

LITERATURE CITED

1. ALBRECHT, H. R. Vetch varieties for soil improvement and seed production in Alabama. Ala. Agr. Exp. Sta. Bul. 253. 1942.

2. BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. Experiments with legumes in Alabama. Ala. Agr. Exp. Sta. Bul. 232. 1930.
3. SNEDECOR, G. W. Statistical Methods. Ames, Iowa: Collegiate Press. Ed. 3. 1940.

NOTES

THE ISOLATION OF ISOGENIC LINES AS A MEANS OF MEASURING THE EFFECTS OF AWNS AND OTHER CHARACTERS IN SMALL GRAINS[1]

SOME years ago in connection with experiments on the effect of awns upon the yield of wheat, a procedure was adopted for developing awned and awnless lines which are identical, or nearly so, for all genes except those involved in the expression of awns. This procedure, though genetically quite simple, has attracted the interest of a number of agronomists, several of whom have urged that it be called to the attention of others confronted with the same or similar problems.

The procedure involves the hybridization of an awned wheat (Kanred) with an awnless wheat (Clarkan). In this cross the expression of awns is governed by a single pair of factors. The awnless condition is partially dominant. In the F_1 all plants are awnless except for the so-called "tip-awns". In F_2 three types of plants, awnless (*AA*), tip-awned (*Aa*), and awned (*aa*), appear in a ratio of 1:2:1. In this, and in succeeding generations until the final selections are made, the two homozygous types are discarded and the bulk stock is perpetuated from the heterozygous tip-awned plants.

Since wheat is a self-fertilized plant and since heterozygosity is reduced by approximately half with each generation of inbreeding, it is assumed that the population after 8 to 10 generations will comprise a number of different lines, each one almost completely homozygous for all genes except the pair involved with awns. By selecting in each generation plants heterozygous for awns, homozygosity in all genes except those governing awns will eventually be attained.

When this point is reached, awned and awnless segregates are to be isolated from a number of different lines. This can be done by growing plant rows from tip-awned and then bulking plants of the two types separately, i.e., homozygous awned and homozygous awnless, for increase and testing in yield trials. The awned and awnless segregates from the same line should be isogenic (identical in all genes) except for the genes involved in awns, and a few additional genes so closely linked that they are not released through crossing-over.

By comparing the awned and awnless members of a number of pairs of isogenic lines, it should be possible not only to measure the general effect of awns, but also to determine whether the effect varies with the genetic background. There are in this particular cross, for example, hard and soft wheat segregates, weak-strawed and stiff-strawed segregates, etc. In each of these categories isogenic awned

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station, cooperating. Received for publication March 25, 1942.

and awnless lines can be compared. By conducting the tests at several localities the effect of awns can be measured on different environmental backgrounds and the interaction of environmental and genetic backgrounds can be studied. If only the effect of awns is of interest, then the lines may be bulked into a single comparison. The same question might be answered by means of a series of back crosses to each parent after the first cross, but this would require considerable work and would not offer the opportunity of studying the genes against several backgrounds as is possible in the proposed method.

Mention has been made of the fact that the two members of an isogenic pair of lines isolated from a population approaching homozygosity will differ not only by the genes governing the expression of the character under observation, but also by additional genes so closely linked to these that they are not separable by crossing-over. Actually, the two members of the pair of lines will differ by a small block of chromatin. In the cross of Kanred×Clarkan, for example, one of the members of each pair of isogenic lines will be of the composition *AA*, the other *aa*. But associated with the former will be a small block of unidentified genes derived exclusively from Clarkan, while with the latter a block of similar size derived exclusively from Kanred. The size of the non-isogenic block will depend upon the position of the *A* locus with respect to chiasmata forming regions. In no case should it be large enough to affect yields or quality perceptibly beyond the effect produced by the *A* gene. In any case the effect is one which may usually be expected to be associated with the *A* gene. From the standpoint of practical plant breeding, it makes little difference whether the effect of awns is due exclusively to the gene for awns or partially to other genes inseparably associated with it.

The procedure here described is also being used in barley in a comparison of hooded vs. smooth awns, hooded vs. rough awns, and rough vs. smooth awns. It is applicable to any situation where the expression of a character is dependent primarily upon one pair of genes and is especially useful when the heterozygote is easily identified and self fertilization is the mode of reproduction.—I. M. ATKINS and P. C. MANGELSDORF, *Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture.*

A WINGED HERBARIUM FOR EDUCATIONAL PURPOSES[1]

THE plant herbarium has unusual possibilities as a medium of education in the development of an agricultural program embracing the improvement of farm crops and pastures and the eradication of noxious weeds. Progressive farm operators endeavor to familiarize themselves with the vegetative and seed characteristics of the more common crop plants and weeds in order that they may recognize

[1]Contribution from the Soil Conservation Service, Research and Operations Divisions, U. S. Dept. of Agriculture. Acknowledgment is hereby given to J. W. Zahnley, Associate Professor of Agronomy and Director of the State Seed Laboratory, Kansas State College, Manhattan, Kan., for helpful criticism in preparation of this manuscript.

pollution in their seed stock, fields of growing grain, and pastures or meadows used for hay or grazing. The successful farmer or farm adviser must be familiar not only with crop plants and their culture, but also with weeds and methods of controlling them.

Crop culture has long been a subject for study by agriculturalists, but it has been only recently in this country that serious and widespread attention has been given the problem of controlling weeds. High schools and agricultural colleges emphasize the value of acquainting those interested in agronomy with the identification, ecological characteristics, economic importance, and best means of controlling pestiferous plants.

Losses due to weeds are far greater than is generally recognized. Three billion dollars has been regarded as a fair estimate of the annual damage done by weeds in the United States. This is far greater than the losses resulting from plant and animal diseases. The seriousness of this problem has been recognized to the extent that several states have enacted laws requiring landowners, public and private, to eradicate all weeds declared noxious by legislative decree. These states are also promoting educational programs leading to control and eradication measures.

Successful and economical control of weeds depends largely upon prompt and accurate identification and a knowledge of their growth habits and ecological relationships. One of the practical and effective aids in this educational program is the maintaining, in an accessible place, of a collection of properly identified plant specimens. Because of the expense and painstaking work necessary to organize and maintain a reasonably good herbarium, it is out of the question for individual farmers or even communities to acquire one, but it is not wishful thinking to visualize the development of a practical plant collection in each Soil Conservation district office, or county farm bureau office, or high school vocational agricultural classroom.

Plant collections have been started at a number of high schools and county agriculture offices. One of the difficulties encountered in organizing these collections has been the preservation of individual specimens in a manner that will permit frequent and convenient use without destruction of the specimen. It is felt that all these requirements have been met in the winged herbarium developed by the Soil Conservation Service at Iola, Kansas.

Soil Conservation Service technicians in eastern Kansas have been collecting plants indigenous to the area for some time. Of the three specimens of each plant collected and pressed, one is sent to the Bureau of Plant Industry in Washington, D. C., for identification, one is sent to Amarillo, Texas, to be included in the Regional Soil Conservation herbarium there, and the other is retained at Iola. Until recently the specimens retained at Iola were mounted on regular 11½ by 16½ inch white, sulfur-free mounting paper, and placed in an herbarium cabinet. They were very inaccessible filed in this manner. Also, insect damage and handling through frequent use was rapidly destroying them. It was soon recognized that in order to obtain maximum value for time devoted to preparation of specimens, a better method of preserving and exhibiting them would

have to be worked out. Inasmuch as the value of such a collection lies in its frequent use by farmers, students, and technicians, it was decided to construct a display case suited to the needs.

The display took the form of a winged display case illustrated in Figs. 1 and 2. The case can be constructed to accommodate any number of wings desired. The one described here has 20 wings which accommodate 18 specimens each. The construction is mostly of wood and can be easily accomplished in any high school manual training department or similar shop by anyone having fair knowledge of simple woodworking.

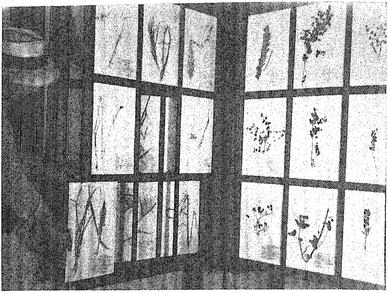


FIG. 1.—Display case showing multiple wing arrangement with cellophane-wrapped specimen ready for placing in frame.

Two triangular-shaped angle iron frames, bolted to a sturdy back support, constitute the top and lower hangers for the wings. Holes are drilled in these hangers to accommodate steel pins fastened to the back edge of the wings. By having the top wing pin ½ inch longer than the lower pin and by having sufficient clearance between the hangers, the wings can be easily removed and packed for moving or other purposes.

The plants are protected by placing one mounted specimen on each side of a 3/32-inch thick binder board and then wrapping with a heavy grade of heat-sealing cellophane. Before the wrapping is sealed a few crystals of insect repellent are placed within. Nine of these packages, which really represent panels, are fitted into each wing much as window panes would be and can be viewed from either side. They are held in the frames by a groove at top and bottom.

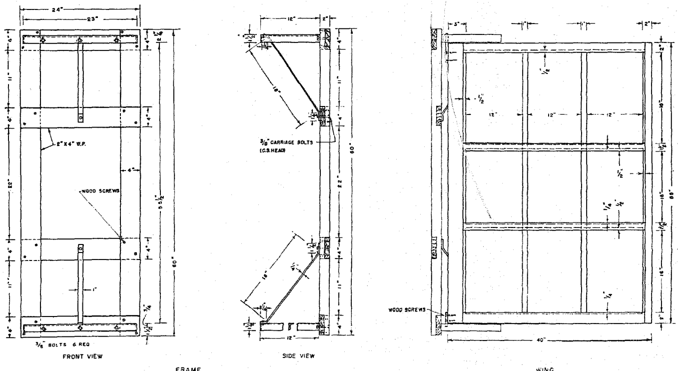


FIG. 2.—Detailed specification for winged herbarium. Working diagrams for the construction of herbarium may be obtained by writing to the authors.

The groove at the top of the frame is deeper than at the bottom so the panel can first be placed in the top groove and then dropped into the bottom groove, leaving it anchored at both ends. Like the wings, these panels can easily be removed for study or other purposes. The cellophane shrinks somewhat when exposed to the air, leaving the wrapping snug and neat.

This type of herbarium display is cheaper and is much lighter and easier to handle than those employing cotton as a backing and glass for protection. The materials for constructing a display case with 20 wings such as the one herein described can be bought for $14.00, and the cost of cellophane and binder board used in making up the specimen panels will average approximately 5½ cents per specimen.—F. G. ACKERMAN and C. E. CREWS, *Soil Conservation Service, Amarillo, Tex.*

DIFFERENCES IN SUGAR CONTENT OF GRASS ASSOCIATED WITH SOIL FERTILITY, GROWTH CONDITIONS, AND GROWTH HABIT[1]

CERTAIN strains of strongly spreading pasture grasses produce seed so sparsely that it is difficult to provide for their economical propagation. Therefore, a study was begun to throw light on some of the differences between free-seeding and sparse-seeding strains and to discover practical methods for increasing seed yield of those that are propagated with difficulty. Pressure of other work made it necessary to discontinue this study. However, a few preliminary findings are presented.

Two selections of red fescue (*Festuca rubra*) were chosen for study. One of these selections which produces an abundance of rhizomes and little seed is designated as the vegetative type. The other, characterized by a bunch habit of growth and heavy seed production, is designated as the seed type.

Twenty-four plants of each of these two selections from seed planted in the greenhouse in the fall were established in 7-inch pots in March. At the time of full bloom sugar accumulation in these plants was compared at two levels of soil fertility and three levels of soil moisture with four plants of each selection at each level. The soil which was used showed a pH reading of 6.5. For pots with high fertility, a 4–12–4 fertilizer at the rate of 800 pounds per acre was mixed with the soil in March. For pots with low fertility no fertilizer was added. Pots with high water had an abundance at all times. Pots with low water had water added only frequently enough to keep plants in good condition.

The results of analyses for total sugars are presented in Table 1.

Observation of the figures in Table 1 show no very consistent association between water supply and sugar content of the plants. However, highly consistent associations appear for both fertility level and growth habit with sugar content. These associations are brought out clearly in Table 2.

[1]Scientific Paper A20. Contribution No. 1826 of the Maryland Agricultural Experiment Station, Department of Agronomy.

TABLE 1.—*Total sugars in 15 grams of red fescue (Festuca rubra) expressed in milligrams of cupric oxide.**

Treatment		Type of selection	
Water	Fertility	Vegetative	Seed
High	High	88.1	34.4
High	Low	57.6	30.5
Medium	High	68.6	67.5
Medium	Low	43.6	52.7
Low	High	86.5	71.6
Low	Low	43.6	No sample

*Green weight basis; 76% moisture.

Figures in Table 2 indicate that plants of both types at full bloom accumulate a larger proportion of sugars in their tissues under conditions of high fertility than they do under conditions of low fertility. It is apparent also that under these conditions the vegetative type accumulates a larger proportion of sugars than the seed type.

TABLE 2.—*Association of average sugar content of red fescue (Festuca rubra) plants with both fertility level and growth habit.*

Fertility level	Growth habit		Average
	Vegetative	Seed	
High	81.1*	57.8	69.5
Low	48.3	41.6	45.0
Average	64.7	49.7	
Difference	64.7–49.7 = 15.0		69.5–45.0 = 24.5

*Sugar content as milligrams cupric oxide to 15 grams of green tissue.

In spite of the fact that the vegetative type produces seed very sparsely in solid stands, isolated plants seed abundantly before they have spread densely over a wide area. Following the observation that sugar content of both types tends to increase with increased soil fertility, samples for analysis were taken from plants in the grass garden after seed was fully developed. The spaced plants which were sampled had been set the preceding fall about 2 feet apart in cultivated rows and the vegetative plants had spread sufficiently for each plant to occupy an area about 10 inches in diameter with only the central part sufficiently mature for seed production and sampling. Seed and seed stems of the samples were separated from leaves. Table 3 shows the results of these analyses.

From the figures presented in Table 3 it appears again that the vegetative type accumulates more sugar than the seed type even in spaced plantings. Also, it appears that the forces which check seed

TABLE 3.—*Association between plant spacing, sugar accumulation, and seed production in both vegetative and seed types of red fescue (Festuca rubra).*

Planting method	Plant type	Seed and seed stalks		Leaves	
		Percentage of sample	Sugar content*	Percentage of sample	Sugar content*
Solid turf	Vegetative	2.2	No sample	97.8	95.5
	Seed	25.3	93.1	74.7	95.2
Spaced	Vegetative	55.6	95.1	44.4	86.2
	Seed	55.5	86.6	44.5	61.8

*Milligrams of cupric oxide from 15 grams of green plant material; 76% moisture.

production in solid plantings are not associated with deficiency of accumulated sugars.—A. O. KUHN and W. B. KEMP, *Maryland Agricultural Experiment Station, College Park, Md.*

AN INEXPENSIVE SOIL STERILIZER

IT became evident early in the grass breeding investigations at the Southern Great Plains Field Station, Woodward, Okla., that some method of soil sterilization was necessary in starting grass plants from seed in the greenhouse. The most drouth-resistant native grasses were particularly susceptible to damping-off in the seedling stage under greenhouse conditions. This difficulty was effectively controlled by heating the soil with low-pressure steam for 2 to 4 hours, although the sterilization was not complete. A highly satisfactory heating chamber, similar in principle to a waterless cooker, was constructed in the station shop at a cost of $24.93 for materials.[1]

The unit has a capacity of 10 flats, each 15½ inches wide, 23½ inches long, and 4 inches deep. Steam produced from heating 3 or 4 inches of water in a pan in the bottom of the chamber with an open three-burner gas stove circulates through the flats which rest on racks made of 1½-inch angle iron set ½ inch from the sides of the chamber. The entire front opens as a door which is sealed with ½-inch rubber hose riveted to the flat surface around the door jamb and held with hinged clamps on either side. The top and bottom of the sterilizer are made of 10-gauge boiler plate and the sides of 16-gauge black iron (Fig. 1).

Only a fractional pound of pressure is developed by proper regulation of the stove. A safety valve was provided on top to release excess pressure, although this has never functioned and it is doubtful if the valve would be needed.

Tests were conducted to determine the length of time heat should be applied effectively to control organisms causing damping-off in grasses. Unsterilized soil was compared with soil sterilized ½ hour, 1 hour, 2 hours, 3 hours, and 4 hours. Soil temperatures, determined

[1]Acknowledgment is given to John J. Brenner, station foreman, and Clarence L. Sheley, shopman, both of the Division of Dry Land Agriculture, for assistance in designing and constructing the sterilizer.

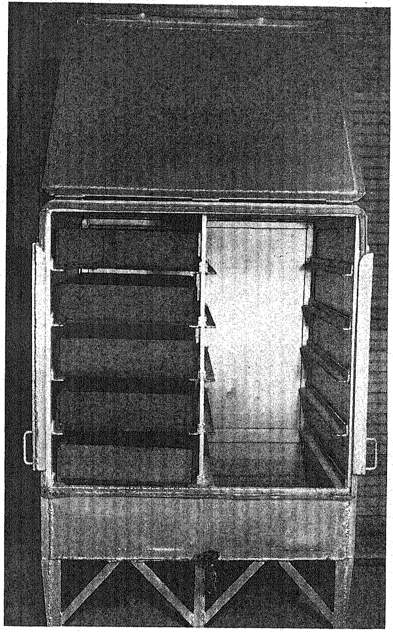


FIG. 1.—An inexpensive soil sterilizer in which steam is produced by heating a shallow pan of water in the bottom of the chamber with an open three-burner gas stove. The steam develops only a fractional pound of pressure and circulates freely around the soil flats. The photograph was taken by L. F. Locke of the Division of Dry Land Agriculture.

by inserting a thermometer in the soil immediately after removal from the sterilizer, were 40°, 70°, 95°, and 95° C, respectively, for the lengths of treatment involved. Quadruplicate samples of 50 seeds each of sand bluestem (*Andropogon hallii* Hack.), side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.), blue grama (*Bouteloua gracilis* (H.B.K.) Lag.), buffalo grass (*Buchloe dactyloides* (Nutt.) Engelm), galleta grass (*Hilaria jamesii* (Torr.) Benth.), and switchgrass (*Panicum virgatum* L.) were planted in each of the five soil treatments and in the untreated check. Emergence counts were made at intervals of 2 or 3 days for 2 weeks. Seedlings which damped-off were removed after being recorded.

TABLE 1.—*Average emergence rates for six species of grasses planted in quadruplicate in soil sterilized by steam for varying lengths of time as compared with untreated soil.*

Grasses	Percentage of emergence						
	Unsterilized	Sterilization time					Increase of sterilized over unsterilized
		½-hr.	1-hr.	2-hr.	3-hr.	4-hr.	
Sand bluestem...	1.5	1.0	17.0	27.5	31.5	35.0	33.5
Side-oats grama.	5.0	13.5	51.5	70.5	75.5	74.0	69.0
Blue grama.....	2.5	4.5	29.5	48.5	39.0	52.0	49.5
Buffalo grass....	13.5	13.0	30.5	26.0	32.5	27.0	13.5
Galleta grass....	0.0	2.0	41.0	56.5	63.5	58.0	58.0
Switchgrass.....	62.0	64.0	76.0	78.0	81.0	87.0	25.0
Average.......	14.1	16.3	40.9	51.2	53.8	55.5	41.4

The test indicated that maximum seedling emergence and establishment were obtained by 4 hours of sterilization, although differences in emergence between 2, 3, and 4 hours of sterilization were slight (Table 1). A slight increase in emergence was obtained with ½ hour of sterilization, and 1 hour was definitely effective. Although 4 hours of sterilization gave maximum germination as an average of all species, the increase over 3 hours was considered insufficient to warrant sterilizing an additional hour. Hence 3-hour sterilization is is now being used satisfactorily for starting grass seedlings at Woodward.

The tests clearly indicate that most of the damping-off occurred previous to emergence. Only 2.4% of the seedling plants damped-off after emergence and the amount was about the same for all treatments, indicating that this was largely due to recontamination in the greenhouse. This has been effectively controlled by covering the seeds at planting time with about ⅜ inch of medium fine sterilized sand. The surface of the sand dries quickly after watering and forms an effective protective seal.—MAURICE L. PETERSON, *Junior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Southern Great Plains Field Station, Woodward, Okla.*

COTTONSEED MEAL ASH AS A FERTILIZER[1]

COTTONSEED meal as a by-product in the manufacture of cottonseed oil is a highly concentrated and well-established feed. This excellent feed is used in large quantities in the countries of northern Europe where we used to export practically all our production at fairly profitable prices. Cottonseed meal is also an excellent fertilizer, but its use by us as such was small because of its comparatively high price.

The war has deprived us of those attractive markets in the northern countries and, as a result, the price of cottonseed meal has tumbled to such a low point (from 600 Rs per kilo to 75) that the producers are beginning to use it as fuel. As a result, we have a new and valuable fertilizer in the trade which is known as cottonseed meal ash. This is similar to what has already taken place in the case of coffee which is being burned and from the combustion is being obtained an ash rich in potash sold under the name of carbonate of potash. However, in the case of coffee, since its combustion occurs in open fields, the heat energy is practically lost and a large part of the potash is leached out by rains.

Cottonseed meal ash is made up in its entirety of phosphates, potash, magnesium, and calcium, with the amount of carbonate practically insignificant. Its value as a fertilizer has been confirmed by some of the producers in various ways and, for this reason, the author decided to prepare this brief article in order to dispel whatever doubts exist as to its true value as a fertilizer.

Some believe the value of the material is due to its phosphoric acid (P_2O_5) content which is soluble in a 2% citric acid solution and to its water-soluble potash (K_2O), forgetting that the 2% citric acid solution which dissolves the phosphoric acid also dissolves a relative amount of potash. Others consider the total potash only, even though recognizing the phosphoric acid content. The former also go even so far as to compare the water-insoluble potash of this ash to the potash contained in the mineral called leucite (silicate of aluminum and potassium) which is not available to crops.

The analysis which follows represents a typical cottonseed meal ash and will help to clarify our viewpoint:

SiO_2	0.92%
P_2O_5	43.60%
K_2O	32.70%
MgO	17.80%
CaO	5.70%
	100.72%

A glance at this analysis shows the fallacy of the contention of those who attribute the value of the potash (K_2O) of the cottonseed meal ash as being due to its solubility in water; and as for comparing

[1]Acknowledgment is made to R. Gomes Pinto and Oskar Jensen for carrying out the analytical work. Translation from the Portuguese by V. Sauchelli, Davison Chemical Corporation, Baltimore, Md.

the remainder with potash in leucite, cottonseed meal ash contains such an insignificant amount of silica, it could not possibly be able to form insoluble potassium silicates. What occurs is this. In the presence of the high temperatures generated in the ovens or furnaces, ortho-phosphates are changed into pyro- and meta-phosphates which are only slightly soluble in water. Quoting from Denigés, "The pyro- and meta-phosphoric acids are not in relation to ortho-phosphatic acid, without some small measure of hydration (but not of oxidation as might be inferred á priori, of that similar product, to wit, phosphoric anhydride); and by a simple loss or gain of molecules of water, these compounds are reversible, the one to the other."

The change from pyro- and meta-phosphates into soluble ortho-phosphates, which can be assimilated by plants is fairly slow when ash is treated with pure water, but when it is treated with weak

TABLE 1.—*Analyses of various samples of cottonseed meal ash.*

Ingredient	Sample No.					
	42,330	42,383	42,388	42,466	43,029	43,080
	Phosphoric Acid, %					
Total P_2O_5	38.87	34.41	34.62	38.25	36.36	35.92
Water soluble	2.35	1.38	1.43	2.38	—	—
Soluble in citrate	11.41	6.88	8.34	10.93	8.24	—
Soluble in 2% citric acid	34.54	31.60	31.34	35.49	33.70	31.85
Soluble in carbonic acid (H_2CO_3)	—	—	—	9.40	—	—
Soluble in ammonium oxalate, 23%*	—	—	—	—	19.85	12.79
Soluble in ammonium chloride, 2N†	—	—	—	—	—	6.93
	Potash, %					
Total K_2O	25.00	24.48	21.88	24.67	23.50	23.42
Soluble in water‡	2.08	2.88	2.19	2.36	—	—
Soluble in water A.O.A.C. method§	4.32	4.65	5.48	4.41	6.72	—
Soluble in 2% citric acid	—	24.18	21.11	21.92	—	—
Soluble in carbonic acid (H_2CO_3)‖	—	—	—	20.01	—	—
Soluble in ammonium oxalate, 23%	—	—	—	—	21.00	21.13
Soluble in ammonium chloride, 2N	—	—	—	—	—	18.64

*Heat for ½ hour 5 grams of the ash with 200 cc of a solution of ammonium oxalate, let cool, transfer to a 250-cc flask, bring the volume up to 250 cc with water, stir, and filter. From the filtrate take aliquot parts for testing P_2O_5 and K_2O.

†Identical procedure as above, using 2N solution of ammonium chloride.

‡Heat 5 grams of the ash with distilled water, allow to cool, bring up to a volume of 250 cc, filter, and take aliquot parts for determining P_2O_5 and K_2O.

§The procedure recommended by the Association of Official Agricultural Chemists for testing K_2O in ashes. Heat for 30 minutes 10 grams of ash with 300 cc of distilled water. Add to the solution previously heated a small excess of ammonia and a sufficient amount of oxalate of ammonia to precipitate the lime present. Allow to cool, transfer to a 500-cc flask, bring up to volume, stir, filter, and from the filtrate take an aliquot part.

‖Five grams of ash in a Stohmann 500-cc flask, 200 cc of water, and while stirring allow a stream of CO_2 to pass through it for ½ hour. Bring up to volume with distilled water, stir for 3 hours, filter, from the filtrate take aliquot parts to determine P_2O_5 and K_2O.

acids, such as 2% citric, or with carbonic acid produced by passing a stream of carbon dioxide (CO_2) in a suspension of the ash in water under normal pressure for a period of ½ hour, or by means of solutions of salts having a weak base such as citrate, oxalate, and chloride of ammonia, the hydrolosis is very rapid more than 80% of the potash changing over in a few minutes from the water-soluble meta- and ortho-phosphate and a large part of the other phosphates are also hydrolized.

The analyses given in Table 1 based on different samples of cottonseed meal ash confirm what has just been said and furnish a standard by which to assess the fertilizer value of the product.

As will be seen from the Table 1, the percentage of P_2O_5 soluble in water is very small, increases in citrate of ammonia, and goes to as high as 90% in the 2% citric acid solution.

The procedure using citrate of ammonia is shown to be inadequate, since the results are very irregular. Even from the above we can verify by calculation that the hydrolosis of the meta-phosphates was very considerable and in sample No. 42,330 it was practically complete.

As to the potash, its solubility in water is also very small and is almost doubled when the A.O.A.C. method is used, due to the ammonium oxalate which increases the hydrolosis and reaches to about 80% and more than 80% when treated with ammonium chloride and carbonic acid, respectively. It reaches to about 90% when treated with oxalate of ammonia and is practically complete in a 2% citric acid solution.

From what has been said, it is believed safe to conclude that the best way to estimate the fertilizer value of cottonseed meal ash is by means of its content of phosphoric acid soluble in 2% citric acid and by its total potash content.

These observations may not be strictly scientific, but my purpose in presenting them is merely to explain to farmers and the fertilizer trade the manner in which it might be possible to assess the fertilizer value of a product of this kind which is appearing in commercial channels under the abnormal conditions which now exist in the world.—PAULO CORREA DE MELLO, *Chief, Scientific Division, Fertilizer Control Laboratories, Institute of Agronomy, Campinas, Sao Paulo, Brazil.*

FURTHER COMMENTS ON USE OF BUFFER COMPARTMENTS TO MINIMIZE SUBSURFACE LATERAL MOVEMENT OF WATER IN FIELD PERCOLATION EXPERIMENTS

TWO questions were raised by G. W. Musgrave[1] in a recent note regarding our paper[2] on downward movement of soil water. The first of these questions, "Was lateral movement 'completely eliminated' and indeed can it be even 'greatly reduced' in all cases by the

[1]MUSGRAVE, G. W. Notes on subsurface lateral movement of water applied to experimental areas. Jour. Amer. Soc. Agron., 34:288–290. 1942.

[2]NELSON, L. B., and MUCKENHIRN, R. J. Field percolation rates of four Wisconsin soils having different drainage characteristics. Jour. Amer. Soc. Agron., 33:1028–1036. 1941.

described and proposed method?" can be answered as follows: Probably not *in all cases*. We are not aware of having maintained that the proposed method would be perfect or successful under all conditions. However, the evidence discussed below makes it quite certain that lateral movement from the innermost compartment was largely or entirely controlled under the soil conditions which existed in the experiments under question.

The second question was, "Can percolation rates be determined in this way?" The answer is, Yes, within the definition of field percolation as given in the first paragraph of our paper. We defined field percolation rate as the minimum or stable infiltration rate determined on soils not only covered, but completely saturated with water after many hours of water application. Further, our results showed that movement of water through the entire profile established the rate observed, so that percolation or movement through, and not merely into, the soil was being studied. If the term "percolation" is restricted to movement of water *out* of a soil profile, then the only correct means of measurement would seem to be with a lysimeter under suction.[3]

Musgrave concludes from the data in Table 1 of his "Notes", that a wetted area 4 feet wide and 6 feet long was insufficient to protect an enclosed inner area 1 foot wide and 2½ feet long. Scrutiny of these data, however, discloses a wide range and large variations between results of infiltration determinations for the individual areas; a variation so great, in fact, that the differences in infiltration rates obtained with the two widths of border used are not statistically significant. The mean difference of only 0.019 inch per hour between the rates with the two respective widths of border is very small when compared with variations of as much as 0.8 and 0.9 inch per hour between individual determinations from which the mean infiltration rates were calculated. In any case, the possibility of establishing real differences in rates of water movement in the field of less than 0.02 inch per hour has yet to be demonstrated.

From the data presented, one cannot conclude that a 4×6 foot wetted area is either more or less effective than a 6×12 foot wetted area. These data illustrate the variability often found in short-time infiltration measurements; a variability much greater in the case of the soils studied by us than was observed in minimum infiltration or "field percolation" measurements. The irregular distribution of stones in gravelly sandy loams may also increase variability in rates and direction of water movement as compared with nongravelly soils.

In the original paper, we presented averages of our field results in graphical form only. It now seems desirable to amplify the graphs with a table of results (Table 1) from the individual determinations which were previously incorporated into the graph and with additional data (Table 2) not included in the original paper.

For the fourth hour, the maximum differences between the results of individual determinations are, on the Spencer, 0.18 inch per hour, and on the Miami, 0.36 inch per hour. In contrast, the maximum

[3]WALLIHAN, E. F. An improvement in lysimeter design. Jour. Amer. Soc. Agron., 32:395–404. 1940.

differences decreased in the last hour to 0.03 and 0.17 inch per hour, respectively. The results obtained with the Spencer in the last hour probably have little actual numerical significance. They indicate only that the rate of water intake was so low as to approach zero. With the Miami, however, it is evident that water intake could be maintained at approximately 0.5 inch per hour on the sites studied, even after prolonged water application.

TABLE 1.—*Water intake for the fourth hour and for the last hour in each of four experimental areas with wetted borders on the Spencer and Miami silt loams.*

Area No.	Spencer silt loam intake, inches		Miami silt loam intake, inches	
	4th hour	Last hour	4th hour	Last hour
1	0.485	0.048	1.37	0.61
2	0.364	0.036	1.06	0.49
3	0.304	0.030	1.16	0.44
4	0.455	0.060	1.01	0.49
Means	0.402	0.044	1.15	0.51

Substantial agreement between replicates as obtained with the four soils studied, while encouraging, presumably would not eliminate the possibility that water might be escaping sidewise below the surface. To test the latter possibility, rates of water intake were determined directly on the impermeable subsoil layers in the field after the upper layers had been removed and using the same buffer compartment method previously employed. The results for three soils are given in Table 2. Unfortunately, the Miami was not tested in this way at the time and place of the experiments in question.

TABLE 2.—*Water intake for the last hour of direct water addition on the subsoils of the Spencer, Marathon, and Superior soils.*

Area No.	Intake, inches		
	Spencer	Marathon	Superior
1	0.012	0.304	0.00
2	0.006	0.392	0.00
Mean	0.009	0.348	0.00

The average rates of intake for the last hour on the subsoils of the Spencer, Marathon, and Superior soils (0.009, 0.348, and 0.00) are to be compared with those for the last hour for the entire profile (0.044, 0.290, and 0.00). The results with subsoil only and with the entire profile do not differ measurably with the Spencer and Superior, and probably not with the Marathon as well. This means that the

final, stable rate of water movement from the inner measuring compartment through the subsoils was essentially unaffected by the presence of the surface layers which ordinarily are of chief importance in short-time infiltration measurements.

Laboratory measurements made with soil cores 3 inches in diameter enclosed in a metal cylinder are reported in Table 1 of our original paper. The percolation rates, given in inches per hour, show that the upper horizons were more permeable than the lower horizons of our soils. However, the rates of water intake into the saturated field soils were comparable with the percolation rates obtained with laboratory cores for the impermeable lower horizons, but not with the upper, permeable horizons. In fact, the rates of percolation through cores from the horizons of lowest permeability correlated well with the rates observed for the entire profile in the field, thus indicating that lateral movement through upper, porous horizons did not seriously affect the rate of intake during later critical periods of the experiment.

Our observations, to be sure, indicate that lateral movement does occur in the field, especially in unsaturated soils. However, in soils already saturated, and on which buffer compartments around the central measuring area are employed, there is little opportunity for lateral movement from the central compartment. Lateral movement into saturated soil would not occur unless (1) the water from the innermost ring would push outward against the water in the pores of surrounding saturated soil more strongly than water from the larger buffer compartments pushed inward, or (2) unless water from the central ring could move down through saturated pores more rapidly than water from the outer buffer compartments, or (3) unless cracks or channels would carry water sidewise en masse. For instance, the wetted border in our experiments had 11 times as great an area as the inner measuring compartment, and, like the inner compartment, the border was supplied with water as rapidly as it drained away. Water from the central area, therefore, could hardly gain a speed or pressure advantage except under the third condition which probably is not general in soils after thorough wetting.

Our experiments, however, were not concerned with unsaturated soils or short-time infiltration. In fact, short-time measurements do not show much difference in rates of water intake between the Wisconsin soils studied when they are at comparable and fairly low moisture contents. On the other hand, differences in field behavior during prolonged rains are quite noticeable. Consequently, the point raised by Musgrave as to the fate of the 30 inches (total) of water which entered the Miami profile during the entire experimental period apparently is not well-taken. The water applied during the first 10 to 20 hours in our experiments was used only to saturate the soil under and around the central ring, and its rate of entry was measured only to determine when this large mass of wetted soil had become saturated, so that a stable minimum rate of intake would prevail.—L. B. NELSON and R. J. MUCKENHIRN, *Department of Soils, University of Wisconsin, Madison, Wis.*

A POWER CLIPPER FOR MOWING EXPERIMENTAL PLOTS

HAND clipping of vegetation, especially of short grasses, is a slow and difficult procedure. A power clipper was, therefore, adapted for harvesting experimental plots used in moisture conservation studies in the eastern Wyoming-Colorado area.

The mixed vegetation of the area usually consists of about 75% blue grama (*Bouteloua gracilis*) and varying percentages of bluestem wheatgrass (*Agropyron smithii*), needle grass (*Stipa spp.*), Sandberg bluegrass (*Poa secunda*), June grass (*Koeleria cristata*), sedges, and forbs. Blue grama here seldom grows taller than 2½ inches, but in seasons of abundant or well-distributed rainfall, some of the other species may reach a height of 30 inches or more.

The clipper which was selected has a sickle and bar like those on a farm mower, but smaller and mounted in front of the tractor. It will clip all vegetation extending above the level of the sickle, no matter what the height. The bar is 42 inches long; however, a light sheet metal guard placed over it reduces width of swath to 15 inches without at all interfering with operation of the machine.

A reel mounted over this open portion presses vegetation into the cutting mechanism and then sweeps it back over the bar into a grass catcher especially built for the mower. Cross pieces of the reel are set with horsehair bristles, which touch the cutter bar in passing over it and gather even short tips of leaves and stems as they are clipped. Reel, sickle, and traction wheels are all driven by the same motor. The machine as adapted is shown in Fig. 1.

Attachment of the cutter bar and reel assembly by means of a single, flexible joint permits this assembly to remain parallel to the ground surface (to float) even if either of the traction wheels rises or falls. At the same time this method of attaching the unit enables the operator to raise the entire assembly by tilting up the forward part of the tractor.

Height of stubble left by the machine is 1 inch on even ground. While clipping at this height is adequate when dealing with taller species of grasses, such as *Stipa* and *Agropyron smithii*, it often leaves a large proportion of the forage produced by short grasses, principally *Bouteloua gracilis* and *Buchloe dactyloides*.

The harvesting of forage on the native range in connection with moisture conservation studies is solely a sensitive measure of the moisture conserved on the different plots during the year. To do this satisfactorily one must clip a major portion of the major species. The short grasses mentioned previously are the major species, while midgrasses occur in mixture in varying quantities. The short grasses vary in height from 1½ to 2½ inches, depending on the year. Therefore, for a study of this nature, adjustments on the mower to cut less than 1 inch above ground would be desirable. Studies designed to simulate grazing might not require such close clipping. Cutting height of the clipper can be somewhat reduced by adjusting tilt of the cutter bar and also by grinding down the sickle guards to reduce their thickness.

Some 300 experimental plots, each about 50 feet long, were har-

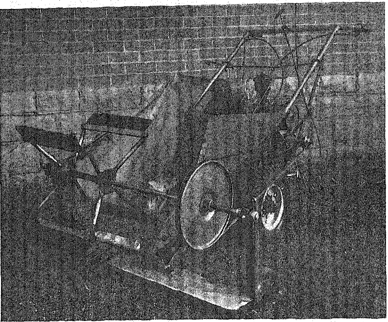


FIG. 1.—The power clipper. The reel and grass catcher, also the shield over a portion of the cutter bar, were attached to a stock model mower.

vested with the machine. Many of these transects crossed contour furrows and pits made with an eccentric disc. Yields were compared with those obtained by hand clipping the same areas in previous years, and in nearly all instances machine harvesting in 1941 was judged to have been satisfactory.

Forbs, treated as a separate portion of the yield, were collected from the transects by hand before the mower was used. Mowing of grass then required but 5 minutes per plot, while in preceding years harvesting it by hand required about 75 minutes per plot.

Experience with the mower in 1941 suggests that its performance would be satisfactory in harvesting stands of grasses of even height, especially such pure stands of taller growth as are encountered in grass nurseries. It should also be very satisfactory in studying yields of mixtures or of pure stands of grasses seeded for pasture or other purposes in regions where annual rainfall is 20 inches or more.

Where use of the mower is at all feasible for experimental work, the time saved over that needed for hand clipping can be used for increasing replications of sample plots. This increase may well be an element in improving experimental lay-outs and thus contribute to reducing experimental error caused by inadequate sampling on native range where wide variations in vegetative density and composition are common.—O. K. BARNES and BRUNO KLINGER, *Soil Conservation Service, Fort Collins, Colo.*

LESPEDEZA IN THE COASTAL PLAIN AREA[1]

GENERAL experience with lespedeza in the Coastal Plain of the Southeast has led most people of this region to the conclusion that the annual lespedezas (*Lespedeza striata* and *L. stipulacea*) are moisture-loving plants and make best growth on low lying soils. Failure to grow or maintain lespedeza on dry or upland soil has been attributed to its lack of adaptation to such environment. A study of the rainfall in countries where lespedeza is indigenous and in places where it has been introduced and is well adapted does not entirely substantiate these conclusions.

Observations last year (1941) on the Coastal Plain sandy soils showed only occasional good growth of lespedeza on high dry soils, while in low and moister soils good growth was common. A study of the previous management of both upland and lowland in which lespedeza was growing showed that fields of good lespedeza on high, dry land were invariably on new ground or on ground that had not been cultivated for several years. Uplands which had been in cultivated crops for a few years grew poor lespedeza and rootknot nematodes were always found on the roots. Lowlands in the Coastal Plain area that regularly grow good crops of lespedeza are usually fields that retain abundant moisture throughout the summer and are too wet for general cropping.

These observations suggest that where lespedeza does well the nematode population is light due to the fact that crops favorable to nematode increase have not previously been grown; or to the fact that winter rains that keep these soils saturated with water for long periods are unfavorable to nematodes. Another explanation might be that lespedeza can tolerate fairly heavy infestation if moisture is plentiful. Annual lespedeza appears unable to tolerate nematodes when associated with drought.

More definite information is needed regarding the injury by nematodes to annual lespedezas when grown under various soil and moisture conditions; and the possibility of growing them in the Coastal Plain area by resorting to rotation with crops that are not susceptible to nematodes should be given further attention.—J. L. STEPHENS, *Coastal Plains Experiment Station, Tifton, Ga.*

BOOK REVIEW

ECOLOGICAL CROP GEOGRAPHY

By Karl H. W. Klages. New York: The Macmillan Company. XVIII+615 pages, illus. 1942. $4.50.

THE author of this volume who is Agronomist at the University and Experiment Station of Idaho, apparently received his inspiration for studies in the field of crop geography from a course in this subject given by Dr. W. L. Burlison at the University of Illinois.

[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Georgia Coastal Plains Experiment Station, Tifton, Ga.

The present book is an outcome of some 18 years of study in this field in various states and the teaching of the subject to agronomy students.

The following brief outline gives some idea of the breadth and scope of the subject matter. Part I deals with the social environment of crop plants and covers matters concerning relationships of crop ecology and economics to other phases of crop study, the historical background of crop production, and relationships between population and agricultural production. Part II deals with the physiological environment of crop plants from the world standpoint, crop adaptation, etc. Part III takes up various ecological factors, such as moisture, temperature, light, atmosphere, and climate as affecting crop production. Part IV deals with the geographical distribution of practically all the important agricultural crops exclusive of horticultural ones. The subject matter is well arranged, references are given at the chapter ends, and the book has an author and subject index.

Some idea of the extent of reference material can be obtained from the fact that there are 130 references on moisture alone, 83 on temperature, etc. In Part IV each crop is discussed from such angles as commercial importance, historical background, climatic, temperature, moisture, and soil relationship, and world distribution. Crops include all the small grains, coarse cereals, legumes, potatoes and root crops, sugar crops, oil crops, fiber crops, forage crops, and miscellaneous crops.

The book brings together material from an unusually wide range of crop information and relates it to world crop geography and ecology. The reviewer knows of no single publication which deals so comprehensively and thoroughly with the subject. Anyone interested in practically any phase of crop production will find a wealth of important and valuable material in the volume. (R. C. C.)

AGRONOMIC AFFAIRS

NEWS ITEMS

Doctor John W. Gilmore, former President of the College of Hawaii, which later became the University of Hawaii, and widely known agronomist, died at Woodland, Calif., on June 25 at the age of 70.

—A—

Doctor F. J. Alway, of the University of Minnesota, having reached the retirement age, was made on July 1 Professor Emeritus in the Division of Soils, after having served 29 years as chief of that Division. He is succeeded by Doctor Clayton O. Rost, who has been Professor of Soils in the same Division, and who, in 1913, came with him to Minnesota from the University of Nebraska.

JOURNAL

OF THE

American Society of Agronomy

Vol. 34 | August, 1942 | No. 8

THE INHERITANCE OF REACTION OF TURKEY-FLORENCE-1 X ORO-1 TO RACE 8 OF *TILLETIA LEVIS*[1]

C. E. Claassen, O. A. Vogel, and E. F. Gaines[2]

In a previous study (4)[3] of the segregates of Oro × Turkey-Florence, a satisfactory genetic analysis of their reactions to three races of bunt could not be made because of insufficient data. The results, however, prompted a repetition of the study in order to obtain the desired genetic evidence for two of the races. The inheritance of reactions to one of the races, L-8, is presented in this paper.

MATERIAL AND METHODS

Crosses were made in 1936, consisting of the three possible combinations among the following three individual parent plants: Oro-1, selected from Oro (C. I. 8220);[4] (Turkey-Florence)-1, selected from Turkey-Florence (C. I. 10080); and Selection 9, selected from Oro × Turkey-Florence, F_3 row 1098 (4). The F_1, F_2, and F_3 generations of the three combinations were grown in the following three years from seed treated with copper carbonate in preparation for the subsequent study.

In 1937 approximately 500 F_0 seeds of each of the three combinations were produced for the purpose of obtaining F_1 plant reactions. Thus, large numbers of all generations from F_1 to F_4 were available for testing under the same environmental conditions.

Approximately 100 seeds of each randomly selected hybrid plant were inoculated with race L-8, the inoculum having been supplied by Dr. C. S. Holton of the Bureau of Plant Industry, U. S. Dept. of Agriculture. The seeds were thoroughly blackened with spores by placing an excess quantity of the inoculum with the wheat in coin envelopes after which they were shaken vigorously.

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Agricultural Experiment Station, State College of Washington, Pullman, Wash. Published as Scientific Paper No. 511, College of Agriculture and Experiment Station, State College of Washington. Received for publication February 17, 1942.

[2]Formerly Research Fellow in Farm Crops, Washington Agricultural Experiment Station; Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Cerealist, Farms Crops Section of Division of Agronomy, Washington Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 694.

[4]C. I. refers to accession number of Division of Cereal Crops and Diseases.

The seeds of the parents and hybrid populations were machine planted approximately 3 inches apart in 20-foot rows, the rows spaced 1 foot apart, on October 18, 1939. One row of each inoculated parent was planted after every 20 rows of hybrid material to serve as a check. A 100-foot row of each parent, uninoculated, was planted through the center of the nursery to check on soil contamination. A similarly long row of each F_0 combination, containing 250 to 275 inoculated seeds was planted to obtain F_1 reactions.

The resultant plants were pulled after the late-dough stage and were grouped into five classes, *viz.*, 0, 20, 50, 80, or 100% infected, according to the method used by Smith (3). Later the tabulated data were reclassified as bunt-free or bunted, according to the method used by Briggs (1). The genetic analysis of the data presented is based upon the latter classification.

The X^2 test for goodness of fit was made according to the method of Fisher (2).

EXPERIMENTAL RESULTS

The winter was mild and there was no noticeable reduction in stand from winter injury.

The uninoculated parental material was found to be entirely free from bunt, indicating that the soil was not sufficiently contaminated with bunt to alter appreciably the results obtained from seed inoculation.

The genetic interpretations are based upon apparent segregations for two pairs of factors for bunt reaction, the two factors having unequal weights. According to this hypothesis, the most resistant variety (T-F)-1, is the double recessive aabb. The other resistant variety, Sel. 9, is aaBB and the susceptible variety, Oro-1, is the double dominant AABB.

The genotypes and reactions of the parents Oro-1, (T-F)-1, Sel. 9, and the F_1, F_2, and F_3 generations of the three combinations, and also those of six randomly selected F_4 families of (T-F)-1 × Oro-1 are shown in Table 1. The frequency distributions of the parent, F_3, and F_4 rows are shown in Fig. 1.

SEL. 9 × (T-F)-1 AND F_4 FAMILY *A* OF (T-F)-1 × ORO-1

Sel. 9 differs from (T-F)-1 in being slightly less resistant to L-8. The frequency distribution of the F_3 of Sel. 9 × (T-F)-1 appears to have resulted from the segregation of a single factor, that of B. The four F_3 rows having higher percentages of bunt than the highest of Sel. 9 are believed to have resulted more from chance than from transgressive inheritance. Although the F_1 reaction indicates that the factor B is dominant for resistance, the F_2 and F_3 reactions suggest it to be dominant for susceptibility. The high degree of resistance shown by the F_1, as compared with that of (T-F)-1, may have been due to hybrid vigor or to chance. This discrepancy is not considered too serious because the difference between resistance and susceptibility is relatively small. On the basis of a single-factor difference, the average of 23.0% of bunt produced by the F_3 is very near the expected (23.2%). The expected figure was obtained as follows:

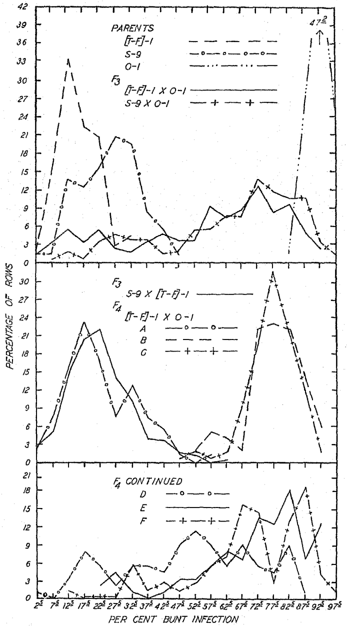


FIG. 1.—Distribution curves of L_8 reactions of Oro-1, (T-F)-1, Sel. 9, the three possible F_3 progenies, and six F_4 families of the cross (T-F)-1 × Oro-1.

TABLE 1.—*Genotypes and distribution of reaction to race L-8 of the three parental varieties Oro-1, (T-F)-1, and Sel. 9; the F_1, F_2, and F_3 generations of the three possible combinations; and also those of six randomly selected F_4 families of (T-F)-1 × Oro-1.*

Cross or parent	Generation	Genotype	Class centers and number of rows in each bunt percentage class																				Total No. of rows	Av. percentage of bunt
			2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5		
(T-F)-1..........	Parent	aabb	1	11	24	16	15	2	3	—	—	—	—	—	—	—	—	—	—	—	—	—	72	16.5
Sel. 9..........	Parent	aaBB	1	1	10	9	11	15	14	6	4	1	—	—	—	—	—	—	—	—	—	—	72	26.3
Oro-1..........	Parent	AABB	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	19	34	18	72	92.7
(T-F)-1 × Oro-1..	F_1*	AaBb	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	68.0
	F_2	AaBb	—	—	—	—	—	—	—	—	—	—	—	2	3	8	3	3	1	—	—	—	20	69.0
	F_3	AaBb	4	10	17	10	17	7	5	10	15	12	12	29	23	28	41	26	31	16	7	—	320	56.8
	F_4-A	aaBb	2	7	15	22	16	7	12	7	5	1	—	1	—	—	—	—	—	—	—	—	95	23.3
	F_4-B	AAbb	—	—	—	—	—	—	—	—	—	—	2	5	4	2	22	23	22	14	6	—	100	78.2
	F_4-C	AAbb	—	—	—	—	—	—	—	—	—	1	2	1	2	11	23	38	25	14	2	—	119	77.8
	F_4-D	Aabb	1	—	3	7	5	2	5	5	4	8	10	8	5	8	5	4	8	1	—	—	89	50.8
	F_4-E	AaBB†	—	—	—	—	2	4	1	—	1	3	3	5	7	6	12	11	16	6	11	—	88	71.4
	F_4-F	AaBB†	—	—	1	—	—	—	4	1	2	1	2	4	5	11	10	2	9	13	3	1	69	70.8
Sel. 9 × Oro-1....	F_1‡	AaBB	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	73.0
	F_2	AaBB	—	—	—	—	—	—	—	—	—	—	—	—	1	3	9	2	5	—	—	—	20	75.0
	F_3	AaBB	—	1	5	2	9	12	10	10	4	5	13	14	20	20	35	30	28	28	8	3	257	64.6
Sel. 9 × (T-F)-1..	F_1§	aaBb	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	12.0
	F_2	aaBb	—	—	1	4	4	8	3	—	—	—	—	—	—	—	—	—	—	—	—	—	20	25.0
	F_3	aaBb	7	13	37	51	55	35	25	10	9	4	3	—	1	—	—	—	—	—	—	—	250	23.0

*Average of 250 plants.
†These are only suggestive.
‡Average of 234 plants.
§Average of 254 plants.

$$\frac{(\text{av. (T-F)-1}) + 2(\text{F}_2 \text{ av. of Sel. 9} \times \text{(T-F)-1}) + (\text{av. Sel. 9})}{4} = \frac{16.5 + 50.0 + 26.3}{4} = 23.2.$$

The F_4 family *A* appears to have the same genetic constitution as the F_3 of Sel. 9 × (T-F)-1, judging from the frequency distributions and average percentages of bunt.

SEL. 9 × ORO-1

The F_3 distribution of Sel. 9 × Oro-1 appears to have been due to segregation for a single-factor, A. The 47.5% class was included in the resistant group because this class contained the smuttiest row of the Sel. 9 parent. This division gives 22.6% of the rows in the resistant group (P = .5–.3).

F_4 FAMILIES *B* AND *C* OF (T-F)-1 × ORO-1

Families *B* and *C* apparently have the same genetic constitution because their frequency distributions and average percentages of bunt are similar. Nearly all of the rows fall within a relatively narrow range of the fairly susceptible classes, indicating these families were homozygous for the genotype AAbb, the fourth possible homozygous genotype of a 2-factor hypothesis.

F_4 FAMILY *D* OF (T-F)-1 × ORO-1

The frequency curve of F_4 family *D* indicates a 1:2:1 ratio. This family appears to have come from the genotype Aabb. The peaks occurring in the 17.5, 52.5, and 82.5% classes appear to represent the genotype aa, Aa, and AA, respectively. The two low points in this distribution might be expected approximately in the 32.5 and 67.5% classes, but they are not clearly evident because of overlapping between genotypes. The fact that the genotype AA of family *D* does not have its mode in the 77.5% class, as in families *B* and *C*, should not be particularly distressing, especially when family *D* has a relatively small number of rows represented by the AA genotype.

F_4 FAMILIES *E* AND *F* OF (T-F)-1 × ORO-1

The frequency distributions of F_4 families *E* and *F*, either singly or in combinations, resemble the F_3 curve of Sel. 9 × Oro-1 more than that of any other frequency curve. The deficiencies of resistant rows, however, may have been due to chance as the populations of these two families were small.

(T-F)-1 × ORO-1

The F_3 frequency curve representing the 320 rows of (T-F)-1 × Oro-1 appears to have resulted from the segregation of the two factors A and B. The rows representing the three resistant genotypes, aabb, aaBb, and aaBB, would be expected to be distributed among the same classes as were those of the F_3 of Sel. 9 × (T-F)-1. In this latter

TABLE 2.—*Summary of factorial analysis of F_3 and F_4 reactions to L-8.*

F_4 families of (T-F)-1 × Oro-1						F_3 families			Genotypes	Percentage class in which average is expected	How determined
A	B	C	D	E*	F*	S-9 × Oro-1	(T-F)-1 × Oro-1	S-9 × (T-F)-1			
—	—	—	—	1	1	1	1	—	AABB	92.5	Oro-1 average is 92.7%
—	—	—	—	—	—	—	2	—	AABb	87.5	Weak factor B is dominant for susceptibility
—	1	1	1	—	—	—	1	—	AAbb	77.5	Average of F_4 families *B* and *C* is 78%
—	—	—	—	2	2	2	2	—	AaBB	72.5	F_2 average of Sel. 9 × Oro-1 is 75%
—	—	—	—	—	—	—	4	—	AaBb	67.5	F_2 average of (T-F)-1 × Oro-1 is 69%
—	—	—	2	—	—	—	2	—	Aabb	52.5	Peak of heterozygous group of family *D* is in 52.5% class
1	—	—	—	1	1	1	1	1	aaBB	27.5	Sel. 9 average is 26.3%
2	—	—	—	—	—	—	2	2	aaBb	22.5	F_2 average of Sel. 9 × (T-F)-1 is 25%
1	—	—	1	—	—	—	1	1	aabb	17.5	(T-F)-1 average is 16.5%

*Suggestive only.

cross 11% of the rows were smuttier than those in the 32.5% class. This latter class contains the smuttiest rows of the aabb genotype as is shown by the frequency distribution of (T-F)-1. Sixty of the 320 F_3 rows of (T-F)-1 × Oro-1 are expected to represent the two genotypes aaBb and aaBB, and seven (11%) of these are expected to be distributed among the classes higher than the 32.5% class. These seven rows plus the 70 in the lower percentage classes total three less than the 80 which are expected to represent all three resistant genotypes.

The portion of the frequency curve containing the intermediate and susceptible rows is almost as expected. The end of the curve representing the susceptible rows, containing the genotype AABB, is approximately one class more resistant than would be expected on the basis of the frequency curve of Oro-1. Likewise, on the basis of the frequency curve of F_4 family *D*, there are more rows in the 37.5 and 42.5% classes than would be expected from the genotype Aabb. These small discrepancies can be due to chance, to the lack of a sufficiently refined technic or to the possibility that more than one minor factor was involved.

The major peak in the 72.5% class represents those progenies having the genotypes Aabb, AABb, AaBb, and AaBB, whose average percentage of bunt, according to the summaries of Table 2, are either in or near the 72.5% class.

SUMMARY

1. Three crosses consisting of the three possible combinations of Oro-1, (Turkey-Florence)-1, and Sel. 9 of Oro × Turkey-Florence were studied for the inheritance of reaction to race 8 of *Tilletia levis*.

2. F_1, F_2, and F_3 generations of all three crosses and six randomly selected F_4 families of (T-F)-1 × Oro-1 were tested for bunt reaction during the same year under identical environmental conditions.

3. Oro-1 is highly susceptible to L-8 and (T-F)-1 and Sel. 9 are both resistant to L-8. A major and at least one minor factor appeared to account for the segregation of reaction of (T-F)-1 × Oro-1. These factors for resistance are carried by (T-F)-1.

4. Crosses of Sel. 9 with Oro-1 and (T-F)-1 indicate that Sel. 9 has only the major factor for resistance.

5. The three parents represent three of the four homozygous genotypes possible under the two-factor hypothesis. Two F_4 families appear to represent the fourth genotype.

6. Segregation of the major factor in conjunction with the minor homozygous resistant factor appears to have been attained in an F_4 family.

7. The average percentage class for each of the nine genotypes was calculated from the average percentages of bunt produced by the F_2 generation plants of the three crosses and by the four homozygous genotypes.

LITERATURE CITED

1. BRIGGS, F. N. Inheritance of resistance to bunt, *Tilletia tritici* (Bjerk) Winter, in wheat. Jour. Agr. Res., 32:973–990. 1926.
2. FISHER, R. A. Statistical Methods for Research Workers. Edinburgh:Oliver & Boyd. Ed. 6. 1936.
3. SMITH, W. K. Inheritance of reaction of wheat to physiologic forms of *Tilletia levis* and *T. tritici*. Jour. Agr. Res., 47:89–105. 1933.
4. VOGEL, O. A., and HOLTON, C. S. Reaction of F_3 progenies of an Oro × Turkey-Florence cross to two physiologic races of *Tilletia tritici* and one of *T. levis*. Jour. Amer. Soc. Agron., 30:55–59. 1938.

INTERRELATIONSHIPS OF LEGUMES AND GRASSES GROWN IN ASSOCIATION[1]

JAMES L. ROBERTS AND FRANK R. OLSON[2]

THE degree of success of mixed cropping depends on the compatibility of the associated plants, not only with respect to habits of top growth, but also with respect to root interrelationships (1).[3] Although harmful root interrelationships may be due to numerous phenomena (2), it now seems probable that the most important of these is competition for nutrients and water. Helpful or symbiotic root interrelationships between legumes and grasses may be due to differences in nutritive requirements or habits of root growth of the associated plants which permit more efficient use of the soil, or to excretion of nitrogen from nodules of the leguminous plant (3, 4). Excretion of nitrogen apparently is of some importance in Finland pastures, but as yet it has not been shown definitely to be of significance in the United States. In spite of some understanding of factors which determine the success of associated growth of plants, so little is known of plant interrelationships, especially in complex mixtures, that pasture seed mixtures still must be considered as compounded more or less empirically.

The purpose of the present investigation was not to search for high-yielding grass-legume combinations, but rather to compare (a) the various legumes as they influence a particular grass; and (b) in considering a particular grass and legume, to compare yields obtained from a unit number of plants on a unit volume of soil grown in mixed stand with yields of the same number of plants on the same volume of soil grown separately. The design of the experiment is such that critical evidence of excretion of nitrogen cannot be obtained. It was originally intended that more critical experiments would follow this preliminary experiment if the results indicated the possibility of appreciable excretion having occurred. However, the nature of the results obtained make it seem wise to publish the preliminary work without additional experimentation.

MATERIALS AND METHODS

On March 18, 1940, red top (*Agrostis alba*), Kentucky bluegrass (*Poa pratensis*), Kansas common alfalfa (*Medicago sativa*), lespedeza (*Lespedeza striata*), Wisconsin Dutch white clover (*Trifolium repens*), white blossom sweet clover (*Melilotus alba*), mammoth red clover (*Trifolium pratense*), and Alsike clover (*Trifolium hybridum*) were seeded in flats of Plainfield sand for later transplanting to Crosby silt loam. Prior to planting, the seeds were soaked in suspensions of appropriate, effective strains of Rhizobia.

[1]Contribution from the Departments of Botany and Agronomy, Purdue University Agricultural Experiment Station, West Lafayette, Ind. Journal Paper No. 7, Purdue University Agricultural Experiment Station. Received for publication March 5, 1942.

[2]Associate in Botany and Assistant in Agronomy and Botany, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 701.

Crosby silt loam was sifted through ¼-inch hardware cloth and limed with the equivalent of 3 tons per acre of a mixture of calcium carbonate, magnesium carbonate, and calcium sulfate (9:6:1). This amount of lime was sufficient to raise the pH of the soil from 5.7 to 7.1 at time of harvest. The limed soil was thoroughly mixed with the equivalent of 1,000 pounds per acre of 0-12-12 mixed fertilizer and placed in flats (34 × 16 × 5 inches). Between April 3 and 8, legumes and grasses were transplanted from the Plainfield sand to these flats. Replacements were made during the following 2 weeks. As the legumes were transplanted, the roots were momentarily immersed in suspensions of nodule bacteria.

Both legumes and grasses were grown alone and in all possible combinations of one legume with one grass. Thus, with 20 plots all possible combinations involving mixtures of not more than two species were obtained. These 20 plots were placed at random in five flats of Crosby silt loam, which were considered to constitute a block. There were four such blocks.

Each plot consisted of 30 test plants, 15 grass and 15 legume plants in the case of mixtures, and 30 plants of a kind where each species was grown alone. The plants were placed in rows, 1½ inches being the distance between rows and between plants within each row. In plots containing mixtures, grasses and legumes were alternated within each row. Border rows of plants between the test plots and the edges of the flats, and between adjacent plots within each flat, were planted and handled just as were test rows, except that these were discarded at harvest.

The plants were watered with tap water, the amount used being determined by visual observation of the condition of the soil. The temperature of the greenhouse was determined by the temperature outside the house, but was never allowed to fall below 65° F.

On June 20, and again on July 22, top growth was harvested from all plots. At the latter date roots were removed from the soil and refrigerated. As time permitted, roots were brought into the laboratory and grass roots separated from legume roots with forceps. This work was done under cold water. Approximately 1 hour was required for the separation of the legume and grass roots from each plot. Harvests of both tops and roots were dried at 100° C and weighed. The tissues of both tops and roots were then milled to pass through a 2-mm sieve and total nitrogen determined.

EXPERIMENTAL RESULTS

The results, summarized in Table 1, show that the weight of 15 bluegrass plants grown on a unit volume of soil was greater when these plants were associated with either Lespedeza or white clover than when in pure stand. In association with sweet clover and alfalfa, the weight of grass was somewhat less than in pure stand. Red clover and alsike clover appear not to have appreciably influenced the weight of bluegrass produced. In general, the behavior of red top in the various associations is like that of Kentucky bluegrass. These differences in behavior of the legumes could have been due to their differing capacities to compete with the grasses for nutrients, or to their differing capacities to supply the grasses with additional nitrogen. There is little doubt that some of the observed differences in the yield of grasses is due to varying degrees of competition exerted by associated legumes. The real question is whether or not the degrees of competi-

tion differ to an extent great enough to account for all the observed differences in the yield of associated grasses.

TABLE 1.—*Influence of associated legumes on dry weight basis and nitrogen content of bluegrass and red top.*

Crop association	Weight of grass (15 plants), grams			Total nitrogen in grass (15 plants), mg			Percentage nitrogen
	Tops	Roots	Total	Tops	Roots	Total	
Bluegrass alone	3.25	5.52	8.77	82.6	71.2	153.8	1.70
Bluegrass+red clover	3.94	4.75	8.69	85.1	89.0	174.1	2.00
Bluegrass+sweet clover	2.64	3.72	6.36	63.2	70.0	133.2	2.11
Bluegrass+alsike	3.99	4.72	8.71	87.6	77.3	164.9	1.89
Bluegrass+Lespedeza	4.49	6.96	11.45	86.2	103.6	189.8	1.65
Bluegrass+alfalfa	3.68	3.53	7.21	85.9	65.5	151.4	2.09
Bluegrass+white clover	5.41	5.75	11.16	111.9	89.9	201.8	1.80
Significant difference*	1.03	1.23	1.95	22.4	26.4	40.3	
Red top alone	6.47	5.17	11.64	136.9	55.1	192.0	1.65
Red top+red clover	6.93	6.41	13.34	166.1	93.4	259.5	1.95
Red top+sweet clover	5.04	4.90	9.94	129.5	74.4	203.9	2.04
Red top+alsike	6.45	6.50	12.95	160.6	92.7	253.3	1.95
Red top+Lespedeza	7.34	7.35	14.69	158.9	102.5	261.4	1.78
Red top+alfalfa	7.25	5.32	12.57	184.7	82.4	267.1	2.12
Red top+white clover	9.05	7.56	16.61	209.9	94.9	304.8	1.84
Significant difference*	1.53	1.22	2.27	47.2	23.5	54.3	

*At the 5% level.

In the absence of a better measure for competition, total dry weights of legume roots and tops produced in the various associations have been used (Table 2). The obvious objection to the use of legume weights in this manner is that the assumption is made that unit weight of legume tissue is a valid criterion of competition, applying equally for each of the several legumes.

When the grass yields are adjusted by covariance to the mean weight of associated legumes (17.16 grams with Kentucky bluegrass and 12.58 grams with red top), the following yields of combined roots and tops of the grasses would be expected:

Associated legume	Red top, grams	Kentucky bluegrass, grams
Red clover	15.51	10.38
Sweet clover	11.17	7.56
Alsike clover	12.62	8.00
Lespedeza	12.54	9.20
Alfalfa	13.34	9.12
White clover	14.88	9.35
Significant difference at 5% level	1.94	1.92

TABLE 2.—*Influence of associated grasses on dry weight basis and nitrogen content of legumes.*

Crop association	Weight of legume (15 plants), grams			Total nitrogen in legume (15 plants), mg			Percentage nitrogen
	Tops	Roots	Total	Tops	Roots	Total	
Red clover	16.97	4.21	21.18	532	122	654	3.08
Red clover+bluegrass	20.19	4.16	24.34	608	114	722	2.97
Red clover+red top	15.35	3.36	18.71	465	89	554	2.96
Significant difference*	3.91	1.16	4.70	87	34	131	
Sweet clover	13.17	3.42	16.59	494	97	591	3.56
Sweet clover+bluegrass	18.16	4.15	22.31	697	131	828	3.71
Sweet clover+red top	13.04	2.91	15.95	496	85	581	3.64
Significant difference*	5.1	1.14	5.79	204	40	237	
Alsike	10.59	2.40	12.99	336	65	401	3.09
Alsike+bluegrass	11.37	2.47	13.84	368	66	434	3.13
Alsike+red top	8.75	1.70	10.45	283	48	331	3.16
Significant difference*	2.01	0.96	2.60	65	30	80	
Lespedeza	6.15	2.01	8.16	166	41	208	2.54
Lespedeza+bluegrass	5.97	1.00	6.97	148	19	167	2.39
Lespedeza+red top	3.86	0.39	4.25	98	8	106	2.49
Significant difference*	1.58	0.85	1.80	39	19	45	
Alfalfa	13.03	6.54	19.57	425	184	609	3.11
Alfalfa+bluegrass	18.61	8.13	26.74	597	230	827	3.09
Alfalfa+red top	14.62	5.67	20.29	471	169	640	3.15
Significant difference*	4.36	1.93	6.13	119	45	150	
White clover	6.55	2.37	8.92	195	68	263	2.95
White clover+bluegrass	7.69	1.13	8.82	235	31	266	3.01
White clover+red top	5.06	0.82	5.88	149	25	174	2.95
Significant difference*	0.98	2.14	1.39	40	21	58	

*At the 5% level.

The greater yields of grass obtained with Lespedeza and white clover (Table 1) obviously may be due to less competition exerted by these legumes. However, since significant differences between yield of grass are found even when the yields of grasses are corrected to uniform weights of competing legumes, it must be assumed that some legumes influence the yields of grass by means other than competition, or that the legumes differ in the competition exerted by equal weights of their respective tissues. If the relationship between legumes and grass in the associations studied is largely one of competition, then of the legumes tested unit weight of red clover and perhaps white clover would appear to suppress the growth of associated grass to a lesser extent than do the other legumes studied.

If excretion of nitrogen has occurred in any of the associations studied, then it seems most likely to have occurred from nodules on red clover, or perhaps white clover. However, evidence for or against excretion of nitrogen having occurred is inconclusive. Increase in percentage nitrogen content of grasses (Table 1) appears to be correlated with growth vigor of the associated legumes and may be due to suppression of growth of grass by the legumes. Greater total nitrogen content of grasses grown in association with legumes, as compared to that of grasses grown in pure stand, is likewise not conclusive evidence of excretion when the test is made in soil, since it might be expected that a greater amount of soil nitrogen would be available to 15 grass plants associated with 15 legumes on unit volume of soil than when associated with 15 other grass plants on unit volume of soil, (i.e., in pure stand).

The results in Tables 1 and 2 are brought together in Table 3 in such a way that the influence of association on the total weight and total nitrogen content of the combined yield of grass and legume is shown. For example, the total weight of 15 bluegrass plants growing in pure stand on one-half unit volume was 8.77 grams and the total weight of 15 red clover plants growing in pure stand on one-half unit volume of soil was 21.18 grams. Thus, the combined yield of red clover and bluegrass when grown in pure stand each on one-half unit volume of soil was 29.95 grams. The total weight of 15 red clover plants and 15 bluegrass plants grown in association on one unit volume of soil was 8.69 + 24.34 = 33.03 grams. The difference, 33.03 − 29.95 = 3.08, is entered in Table 3 as increase in dry weight due to associated growth.

TABLE 3.—*Influence of associated growth on the total weight and total nitrogen content of produce.*

Crop	Differences between yield of 30 plants in pure stands* and 30 plants in mixed stands†					
	Weight in grams‡			Total nitrogen content in mgs		
	Tops	Roots	Total	Tops	Roots	Total
Bluegrass and red clover	+3.91	−0.83	+3.08	+79	+8	+87
Bluegrass and sweet clover	+4.38	−1.07	+3.31	+184	+33	+217
Bluegrass and alsike	+1.52	−0.73	+0.79	+35	+7	+42
Bluegrass and lespedeza	+1.06	+0.43	+1.49	−15	+10	−5
Bluegrass and alfalfa	+6.01	−0.40	+5.61	+175	+41	+216
Bluegrass and white clover	+3.30	−1.01	+2.29	+69	−18	+51
Red top and red clover	−1.16	+0.39	−0.77	−37	+4	−33
Red top and sweet clover	−1.56	−0.78	−2.34	−4	+7	+3
Red top and alsike	−1.86	+0.63	−1.23	−32	+20	−12
Red top and lespedeza	−1.42	+0.56	−0.86	−47	+14	−33
Red top and alfalfa	+2.37	−0.72	+1.65	+93	+13	+106
Red top and white clover	+1.09	+0.84	+1.93	+27	−3	+24

*15 grass plants and 15 legume plants each in pure stand on one-half unit area.
†15 grass plants and 15 legume plants in mixed stand on unit area.
‡A plus sign indicates increase due to association, a minus sign decrease due to association.

It should be remembered that gain due to association is the difference between dry weight or total nitrogen in the yield from pure stands, each plant being grown on one-half unit area of soil, and yield of the mixture over unit area of soil. When the test of gain due to associated growth is made in this way, greatest gains due to associated growth are normally expected to occur when plants varying most widely in growth vigor and ability to compete are mixed, since in spreading the plant of greater inherent growth vigor over the greater area, more efficient use is made of the total soil area involved. In our results, this is illustrated best by the fact that the coefficient of regression of top weight of legumes (average of all legumes studied) on total weight of associated bluegrass is −2.04 grams of legume tissue per gram of grass tissue. That is, when an average legume suppresses the dry weight of associated bluegrass by 1 gram, the more vigorous legume was expected concurrently to gain 2.04 grams of dry matter in foliage. Thus, judging only from differences in inherent growth vigor of the legumes and grasses, greatest gains due to association are to be expected in red clover-bluegrass, sweet clover-bluegrass, and alfalfa-bluegrass combinations. Actually, greatest gains are found in sweet clover-bluegrass and alfalfa-bluegrass combinations (Table 3). Failure of the red clover-bluegrass combination to show expected gains in dry weight and total nitrogen content is understandable when it is considered that per unit dry weight of legume tissue, less competition with bluegrass was exerted by red clover than by any of the other legumes studied.

The greater yield of a plant mixture over the combined yield of its component plants growing in pure stand in some cases has been incorrectly interpreted to be evidence of excretion of nitrogen from legume nodules. Considerable care must be exercised in the conduct of such experiments to prevent the effect of relative inherent growth vigor of component plants in the mixture from obscuring lesser effects.

SUMMARY

Six legumes and two grasses were grown in the greenhouse in all possible pure stands and combinations of one grass with one legume.

No cases were observed where both legume and grass were either benefited or injured by associated growth as compared to growth in pure stands. In general, when one component of a mixture produced more dry weight or total nitrogen in mixture than in pure stand, the other component produced less when in mixture than in pure stand.

Differences in the yield of a grass in the associations studied could all be explained by differences in the amount of associated, competing, legume tissue, with the possible exception of relatively high yields of grass in association with red clover.

In several grass-legume mixtures, greater yields of dry weight and nitrogen were obtained from mixtures on unit area of soil than from pure stands of a grass and a legume each on one-half unit area. Largest gains due to association occurred when a legume with vigorous growth habits was associated with a grass with weak growth habits. Gains in dry weight and total nitrogen due to associated growth of a grass and

legume are believed to have resulted from spreading the plants with vigorous growth habits over a greater soil area, thus making more efficient use of the total soil area involved.

LITERATURE CITED

1. AHLGREN, H. L., and AAMODT, O. S. Harmful root interactions as a possible explanation for effects noted between various species of grasses and legumes. Jour. Amer. Soc. Agron., 31:982–985. 1939.
2. LOEHWING, W. F. Root interactions of plants. Bot. Rev., 3:195–239. 1937.
3. PAPADAKIS, J. S. Small grains and winter legumes grown mixed for grain production. Jour. Amer. Soc. Agron., 33:504–511. 1941.
4. VIRTANEN, A. I., and v. HAUSEN, S. Excretion of nitrogenous compounds from the root nodules of leguminous plants. Nature, 135:184–185. 1935.

THE RELATION OF VARIOUS TYPES OF VEGETATIVE COVER TO SOIL DRIFT[1]

ALBERT E. COLDWELL, PAUL R. LOEWEN, AND CHARLES J. WHITFIELD[2]

THE first demonstration project for the control of wind erosion in the United States was established by the Soil Conservation Service in August 1934 in the vicinity of Dalhart, Texas. The project comprised about 47,000 acres and was located 10 miles northeast of Dalhart, Texas. In January 1936, studies were started by the Division of Research, Soil Conservation Service, to determine the causes of soil blowing and the development of methods for its control. Emphasis during the first year was placed on the control and stabilization of sand dune land.[3]

Erosion in the vicinity of Dalhart is principally caused by winds of high velocity. Some water erosion occurs during intense rains, but it is not the serious problem that wind erosion is.

Previous to September 1937, detailed measurements of wind erosion made on two small plots showed that soil moves from land without vegetative cover and accumulates where there is cover; also, that hard, bare ground loses soil by sheet wind erosion a good deal more rapidly than would be indicated by casual observation.

These studies, however, were felt to be inadequate as a measure of the erosion occurring in different kinds of cover. For this reason it was decided to measure erosion along straight lines of comparatively great length, which would cross fields having varying conditions and types of cover. The results of such measurements are discussed in this paper, and they cover the period from September 1937 to October 1940. This period includes the three blowing seasons of 1937–38, 1938–39, and 1939–40.

CLIMATE

The most important climatic factors in the study of wind erosion are precipitation and wind velocity, with temperature playing a minor part.

The precipitation in the Dalhart vicinity is very irregular and averages about 17½ inches per year. Great portions of each year's precipitation usually occur in several very intense rains. Table 1 shows the precipitation which occurred near Dalhart during the years 1937 to 1940, inclusive, as compared with a 31-year average as measured at the Dalhart Dry Land Experiment Station.

The Southern Great Plains are characterized by a windy season which usually begins in February, reaches a peak in March or April, and comes to a close in May or June. Most of the high velocity winds occur during the warm part of the day,

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Texas. Received for publication March 28, 1942.

[2]Assistant Agricultural Engineer, Operations Division; Cooperative Agent; and Senior Soil Conservationist, Research Division, respectively.

[3]WHITFIELD, CHARLES J. Sand dunes of recent origin in the Southern Great Plains. Jour. Agr. Res., 56:907. 1938.

———. Sand dune reclamation in the Southern Great Plains. U. S. D. A. Farmers' Bul. 1825. 1939.

between 10:00 a.m. and sundown, but they occasionally continue throughout the night. High winds have sometimes blown continuously for several days.

Table 2 gives the average monthly wind velocity as measured near Dalhart for the years 1937 to 1940, inclusive. It should be realized that a table of monthly averages does not give a very representative picture of the wind conditions. The wind comes in irregular periods of high and low velocity so that, for example, during any given month, 80% of the miles of wind might occur in 25% of the time. Winds have been measured on the Southern Great Plains which reached average velocities as high as 85 miles per hour for a 30-minute period.

It was found that dust storms often occurred when the wind velocity exceeded 16 miles per hour and that at Dalhart the wind blew at a velocity of 16 miles per hour, or more, 14.2% of the time in 1938 and 13.8% of the time in 1939. Table 3 gives a summary of the number of dust storms that occurred at or near Dalhart each month from 1937 to 1940. Also indicated are the severity and duration of the storms. It can be seen readily that a close relationship exists between the number of dust storms and wind movement. A comparison of Tables 2 and 3 shows that more storms occur in March and April when wind velocities are higher than at any other time.

SOILS

The soils on the Dalhart Project are divided into two main classes. The eastern side of the project has deep, heavy to medium textured soils. Their surface texture varies from loam to clay, with clay loam and silty clay loam predominating. These are the soils on which most of the engineering treatments for the conservation of moisture were applied—terraces and contour tillage—and all comparisons of such treatments in this paper refer to this soil condition.

These heavy to medium textured soils are not greatly affected by wind erosion when they have good structure and are high in organic matter, but when they do get into a blowing condition they contribute to the most serious type of wind erosion. Because of the fineness of their particles, the wind gets this kind of soil high into the air and carries it in the form of dust far from its original location. This type of wind erosion literally causes a "dust storm" as distinguished from a "sand storm".

The western side of the project has deep, sandy soils, varying in texture from loamy sands to sandy loams. Because of their lack of structure, these soils are decidedly susceptible to wind erosion, but the heavy particles have a tendency to stay near the ground and to accumulate at the first obstruction, such as a weed, that they come in contact with. This is the way hummocks, dunes, and fence row drifts are formed and it is this type of soil which contributes to the "sand storm".

RESULTS AND DISCUSSION

The erosion that occurred in the Dalhart vicinity was considered to be equal to the change in elevation of the ground surface. This was measured by determining the profile of straight lines of various lengths. Elevations were measured at 10-foot intervals along these lines before and after each blowing season. In all, 16,493 readings of seasonal change in elevation were taken on the Dalhart Project alone, while several thousand more were made on the Amarillo Experiment Station and the Dalhart Substation.

TABLE 1.—*Monthly precipitation in inches near Dalhart, 1937–1940, compared with long-time average.**

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1937	0.00	0.04	0.84	0.63	5.08	1.61	1.29	0.65	1.85	0.91	0.02	0.31	13.23
1938	0.00	0.31	0.52	1.06	0.97	1.26	1.63	1.68	3.25	2.35	0.00	0.43	13.46
1939	1.46	0.18	0.11	2.22	1.62	1.99	2.71	1.89	0.35	0.56	0.02	1.20	14.31
1940	0.12	0.29	0.16	0.46	1.68	0.98	1.32	2.73	1.35	0.00	3.69	0.29	13.07
31-yr. av.	0.20	0.34	0.71	1.60	2.78	3.01	2.28	2.53	1.52	1.60	0.49	0.43	17.50

*Records for 1937, 1938, and 1939 are the average of 10 rain gages on the Dalhart Project. Records for 1940 are the average of four gages on the Sand Dune Research Station. The 31-year average is from Dalhart Dry Land Experiment Station.

TABLE 2.—*Average monthly wind velocity in miles per hour at and near Dalhart, Texas, 1937–1940.**

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly average
1937	8.40	9.86	10.81	10.03	9.22	9.57	8.05	7.93	7.35	7.92	7.48	7.50	8.68
1938	8.56	8.80	12.11	13.51	11.03	9.72	7.90	8.98	6.49	8.35	9.41	8.67	9.46
1939	9.13	9.98	9.55	11.42	9.36	9.49	7.83	9.46	10.10	10.28	8.31	7.84	9.40
1940	7.40	10.72	11.24	12.42	10.62	12.30	10.85	9.93	10.41	10.63	10.16	9.26	10.50

*From January 1937 to July 1939 anemometer was 51 feet above ground level on top of building in Dalhart. From August 1939 to December 1940 anemometer was 18 feet above ground on a tower support 3 miles southwest of Dalhart.

TABLE 3.—*Dust storm data including number of dust storms by months, storms causing moderate and severe soil damage, and duration during the years 1937–1940, Dalhart, Texas.*

Month	1937			1938			1939			1940			Duration of storms, hours			
	No. of storms	Soil damage		No. of storms	Soil damage		No. of storms	Soil damage		No. of storms	Soil damage					
		Mod.	Sev.		Mod.	Sev.		Mod.	Sev.		Mod.	Sev.	1937	1938	1939	1940
Jan.	6	2	1	5	5	—	2	1	1	—	—	—	28	57¼	13	—
Feb.	9	2	3	4	4	—	7	2	3	7	1	1	100	21¾	45	51
Mar.	11	1	5	14	13	1	4	—	1	14	3	2	143	133½	23½	85½
Apr.	16	13	2	15	12	3	16	3	1	16	6	4	114½	149	73	95
May	8	7	—	11	10	1	8	7	—	7	—	1	42	80¾	34	38½
June	5	4	1	7	7	—	6	4	2	7	3	—	21¼	40	30½	53
July	2	1	1	3	—	—	1	1	—	6	2	—	2:10	1¾	4	19
Aug.	1	1	—	3	—	—	3	—	—	4	2	1	3	22	12½	17
Sept.	1	1	—	0	—	—	2	1	—	4	—	—	6	0	9	19½
Oct.	4	3	1	0	—	—	1	—	1	4	1	—	20½	0	6	25
Nov.	4	2	1	7	1	1	3	—	—	3	2	—	32	25	12	15
Dec.	0	—	—	2	1	—	3	—	—	3	—	—	0	4	18½	16
Summary	67	37	15	71	53	6	56	19	9	75	20	8	512:25	535	281	434

During each of the three years that measurements were made, soil was lost from the project by wind erosion. Over the area as a whole, 5,135 readings showed that for the season 1937–38 the average soil loss was 0.32 inch; 5,687 readings made during the period 1938–39 gave a loss of 0.60 inch; and in 1939–40, 5,671 readings showed a loss of 0.04 inch. A breakdown of the data indicates that, in general, cultivated land with no cover, dirt roads, areas infested with silver leaf nightshade, *Solanum elaeagnifolium* Cav., wheat lands with poor stand, and milo maize had the greatest soil loss (Table 4). Although not shown in the table, indications secured from a few measurements were to the effect that corn, pea, and bean land was also highly susceptible to soil drifting.

The measurements further indicated that for at least two of the three years wind blown material tended to accumulate in hummocks, fence rows, weeds, broomcorn, cane, and sudan stubble (Table 4).

TABLE 4.—*Average soil loss or gain in inches per year that occurred on the various types of land use during each of the three blowing seasons.*

Land use	Av. soil loss or gain in inches per blowing season			Total number of 10-foot readings
	1937–38	1938–39	1939–40	
No cover	−2.98	−2.04	−0.26	2,214
Roads	−0.30	−1.80	−0.20	118
Silver leaf nightshade	−2.24	−2.88	+0.06	164
Wheat*	+0.64	−2.16	−1.20	1,077
Milo maize	−0.24	−0.24	−0.34	5,075
Hegari	+0.14	−0.24	−0.14	2,443
Hummocks	+1.56	−0.60	+2.39	829
Fence rows	+1.21	−3.36	+4.38	32
Weeds, some grass	+0.41	−1.67	+1.03	1,045
Broomcorn	+0.48	+1.08	+0.30	405
Cane	+1.16	+0.30	−0.72	610
Sudan	+0.72	+0.36	−1.30	589

*Good stand, 1937–38; failure, 1938–39; poor to fair stand, 1939–40.

One of the most interesting aspects of these studies is shown in the consistent tendency for milo maize to lose soil. This is probably due to the fact that this crop is grown for grain and as a result is not planted as thickly as sorghums grown for forage. Experiments at the Sand Dune Research Station indicate that when the thickness of planting can be controlled, milo maize compares very favorably with other sorghums in preventing erosion.

For the fields measured, losses and gains were grouped and averaged for each condition and type of cover. Fields with fairly uniform cover were rather consistent as to their soil losses; however, other fields with hummocks and spots of hard bare ground were highly variable as to soil losses or gains.

WIDTH OF ROW VS. SOIL DRIFTING

In order to determine the effect of width of row on soil drifting by wind, a study was initiated in June 1938 at the Sand Dune Ex-

perimental Area near Dalhart, Texas. Three plots were laid out end to end and in an east-west direction in order that they would be equally exposed to the prevailing winds which are from the south and southwest. The loamy fine sand and fine sandy loam soils on which the plots were established had been exposed to wind action for several years, and as a consequence, the surface was covered with sandy hummocks. All three plots were harvested at the same time by using a broadcast binder. An 8- to 10-inch stubble was left on all fields and the stalks or bundles were removed.

Erosion measurements showed that both the lister drilled and drilled plots made actual soil gains of 0.5 inch and 0.4 inch, respectively, while the listed area lost soil material amounting to 0.6 inch. Soil on the listed area was not only constantly shifting during the blowing season, but some of it actually blew into surrounding cover. This soil movement has prevented the growth and establishment of a weed cover to anything like the extent that these annuals developed in the other two areas.

TERRACES AS OBSTRUCTIONS TO WIND

The terraces near Dalhart were generally about 18 inches in height, with the cross section of the fill above natural ground surface about 25 square feet. The upper and lower basins made a total width of disturbed soil of about 50 feet.

It was found in these erosion measurements that on terraced fields the terraces, including ridge and basins, had a tendency to accumulate soil while the intervals between the terraces lost soil. These measurements were made on three cultivated fields and one idle field. On the idle field Russian thistles grew readily on the terraces but were slow in taking root on the badly eroded soil between terraces. As a result, the intervals between terraces lost an average of 0.30 inch of soil per year, while the terraces gained an average of 1.12 inches of soil per year during the 3-year period. Six hundred and eighty-four 10-foot readings were made on intervals between terraces and 180 10-foot readings on the terraces themselves. The terraces collected an aggregate amount of soil practically equal to the aggregate amount lost by the intervals between terraces.

Regarding the cultivated fields, both the terraces and the intervals between the terraces lost soil, although the latter lost much more than the former. As a result of 594 readings on the terraces, it was found they lost an average of 0.10 inch of soil per year, while the intervals between terraces lost an average of 0.52 inch of soil per year, as measured by 3,826 readings.

DIRECTION OF ROWS

Erosion measurements show that there is apparently a significant difference in the loss of soil that occurs when rows run into the wind and when they do not.

For contoured fields it was found from 2,653 readings that rows running generally northeast and southwest, the direction of prevailing winds, lost 0.28 inch of soil per year on the average. Rows running

generally northwest and southeast lost an average of 0.16 inch of soil per year, as shown by 1,116 readings.

For straight-row fields, rows running north and south, lost 0.16 inch of soil per year and rows running east and west 0.01 inch of soil per year. Neither of these is the direction of prevailing winds, although many bad storms come from the north, a particularly severe one having occurred during the period represented by these measurements.

These results, when compared with other factors in wind erosion, indicate that the direction of rows plays only a minor part in changing the amount of wind erosion that occurs. Other changes could be made that would easily overcome this difference caused by direction of rows; however, this problem is one of greatest importance to be overcome in the Southern Great Plains before contour cultivation for moisture conservation achieves the popularity it otherwise seems to merit.

EFFECT OF SEASON ON EROSION ON NATIVE PASTURE

The results which were obtained on the demonstration project reflect only the erosion which occurred between measurements made at varying times of the year, but which were supposed to reflect the erosion that occurred during the blowing season. Indications that wind erosion occurs rather steadily throughout the entire year were found by measurements on the Sand Dune Research Station.

The pasture in which this plot was established comprised mostly blue grama and side-oats grama before the blowing season of 1939, when the experiment started. There was no grazing on the pasture and its cover became better during the following two years, 1939 and 1940.

Table 5 shows the removals and accumulations that occurred on this pasture during three vegetative seasons, two of which approximated blowing seasons and the other represented a growing season when plant cover was abundant on the ground.

TABLE 5.—*Seasonal accumulation or removal of soil which occurred on native pasture at Sand Dune Research Station, 1939–40.*

Interval during which erosion occurred	Average soil loss or gain in inches during interval
Feb. 24 to June 9, 1939	−0.54
June 9, 1939, to Feb. 28, 1940	+0.65
Feb. 28 to June 4, 1940	−0.24
Entire period	−0.13

Table 5 indicates that the tendency of pasture land to hold its own against wind erosion is due to its ability to accumulate soil when there is good vegetative cover on the ground. The source of this soil might be neighboring cultivated fields or the settling dust from the air as the result of winds which occur outside the time which is generally considered as the blowing season. Dust storms may occur in any

month of the year, but the blowing season is spoken of as the months when they are likely to be frequent.

SUMMARY AND CONCLUSIONS

A 47,000-acre demonstration project for the control of wind erosion was established by the Soil Conservation Service, U. S. Dept. of Agriculture, in 1934 in the vicinity of Dalhart, Texas. In 1936, a research station, consisting of 912 acres, was established near Dalhart to study the causes of wind erosion and to develop methods for its control. At both of these locations studies were made of the change in elevation of ground surface of certain types of land from year to year. This change in elevation was caused largely by wind action and was found to vary considerably with different types of vegetative cover.

About 16,000 10-foot readings were taken on the demonstration project and several thousand other similar readings were taken at the Sand Dune Research Station. These were made during the years 1937 to 1940, inclusive, all of which were years of below normal rainfall. It was found that

1. The amount of soil blowing from idle or abandoned lands showed a closer correlation to the precipitation that occurred during the previous years than did crop lands.
2. Milo which was harvested with a combine or header type machine suffered much less from erosion by blowing than did milo which was hand headed.
3. Certain crops, such as broomcorn, cane, and sudan, did not lose soil because of the fact that they are usually planted thickly. Crops such as hegari, milo, kafir, and corn lost a considerable amount of soil, apparently because these crops are usually planted rather far apart in order to produce a grain crop. When the spacing of sorghum crops was controlled, differences such as this were not so apparent.
4. Wheat was variable in its ability to control wind erosion, depending entirely upon the kind of stand obtained.
5. The removal of soil from rows which ran parallel to the direction of the prevailing wind was somewhat greater than from rows which were at right angles to the prevailing wind. This difference, however, was slight in comparison to the differences caused by other factors.
6. It is indicated that terraces without vegetation on their surface do not have much effect in preventing wind erosion. When the vegetation on the terrace was heavier than it was in the intervals between terraces, however, there was a definite tendency for terraces to collect most of the soil lost from the intervals between.
7. Weeds were variable in their ability to collect soil and resist erosion. The effect of Russian thistles depended on their growth, small thick stands accumulating soil during most of the blowing season, while large thistles broke away from their roots and left the ground bare. Silver leaf nightshade which is becoming a

serious pest in the Dalhart vicinity was generally an exceedingly poor cover crop, often being no better than bare ground. Other weeds had a consistent tendency to accumulate soil during the blowing season.

8. Since winds of high velocity may occur in any month of the year, either removal or accumulation of soil may occur continually throughout the year. Whether a given field loses or accumulates soil, depends upon its vegetative cover at the time of each high wind.

INFLUENCE OF LEGUMINOUS PLANT ADDITIONS ON THE ORGANIC MATTER CONTENT AND AVAILABLE NUTRIENT SUPPLY OF SOUTHERN SOILS[1]

FRANK MOSER[2]

COTTON farming in the Southeast has greatly favored erosion and the reduction of the organic matter content of the soil. During the past decade the Agricultural Adjustment Act and Soil Conservation Service have emphasized the growing of legumes as an effective means of providing necessary organic matter for erosion control and soil improvement. Leguminous cover crops have been stressed for soil improvement, but inasmuch as many of the legumes recommended as soil conservers are also good feed crops, they are often fed and consequently are not beneficial to the soil unless the plants produced therefrom are returned. Legumes have high nutrient requirements for calcium, phosphorus, and potassium and in many cases the nutrients removed may be greater than those absorbed by the cotton plant. Thus, unless they are used in a manner that returns organic matter, very little benefit will be derived from their growth.

The practice of growing winter cover crops is very desirable for the South as a good cover restricts erosion and the leaching of plant nutrients during the open winter months. Crimson clover and vetch are the commonly used crops for this purpose and usually produce considerable green plant material to be turned under for the succeeding crops. Lespedeza, crotalaria, and soybeans are good summer cover crops, but in order to provide protection against erosion during the winter months, the plants must be allowed to remain on the soil and form a natural mulch. The protection afforded by mulches against erosion has been previously reported (8)[3] and shows that 4 tons of crimson clover hay applied as a mulch reduced runoff and erosion to very low amounts as compared with the same amount of crimson clover incorporated with the soil. Lespedeza (8) also gave a marked reduction of water and soil losses during the winter months where the plant residues had been left to form a natural mulch. Such action is characteristic of close-growing plants as lespedeza and leaf litter mulches accumulate where this crop is included in the rotation for several years even when the hay is removed. This natural mulching by plants is a desirable soil conservation practice and is advisable rather than applying the mulch artificially as hay. In this present investigation plant materials were applied as green manures, hay mulches, and incorporated treatments to determine the effect of these different methods of adding organic material on the organic matter content, the available soil nutrients, and crop yields. Samples for the chemical analysis and greenhouse cultures were collected for

[1]Technical contribution No. 95 from the South Carolina Experiment Station, Clemson, S. C. Received for publication April 1, 1942.
[2]Associate Agronomist.
[3]Figures in parenthesis refer to "Literature Cited", p. 719.

study from areas where certain legumes had been used in strip-cropping rotation and also from experimental plots designed to study the effects of leguminous plant material on the soil.

EXPERIMENTAL PROCEDURE

Soil samples for determining the effectiveness of organic matter applied as mulches, accumulated as plant residues, and incorporated with the soil were secured from experimental plats initiated in 1939 to study the effect of these various practices. Other samples were taken from field experiments designed to determine the cumulative effect of continuous fertilizer, manure, and green manures on soil.

Soil samples were also collected in April 1938 from cooperators' farms located in the South Tyger River Project area near Spartanburg, S. C. These were secured to study fertility levels resulting from leguminous residues accumulated under strip-cropping rotations. Soil samples were taken from various terrace intervals where respective legumes had been grown, and from adjacent terrace intervals where no legumes had been included. Nitrate nitrogen was determined by the phenol-disulfonic acid method (1), acid-soluble phosphorus according to the method of Truog (10), and replaceable potassium by the procedure of Volk and Truog (11). Organic carbon was determined by the dry combustion method (1), while yield data were secured either from field plots or from pot experiments using sorghum or rye as the indicator crop.

ORGANIC MATTER CONTENT OF SOIL IN RELATION TO LEGUMINOUS ADDITIONS

The average amount of organic matter in the cultivated soils collected for this study in the Piedmont section of South Carolina is shown in Table 1 to be 1.11%, while the use of lespedeza, vetch, and crimson clover in strip cropping and regular rotations have increased the amount to 1.68%, 1.47%, and 1.69%, respectively, for these three green manure crops. Earlier experiments (5) showed that soils managed according to soil conservation practices have also increased in organic matter. Vetch and lespedeza used as a winter and a summer cover crop on a Cecil clay loam raised the organic content from 1.20%

TABLE 1.—*The effect of various legumes used in strip-cropping rotations on available soil nutrients, organic matter content, and yields of rye grown in greenhouse pot cultures.*

Legume in strip-cropping system	Rye yields, grams per pot	Organic matter content, %	Available soil nutrients determined by laboratory methods			
			NO_3N		P, p.p.m.	K, p.p.m.
			Initial, p.p.m.	After incubation, p.p.m.		
Check (no legume)	7.5	1.11	1.0	17	19	64
Lespedeza	15.0	1.68	2.2	50	25	109
Vetch	19.9	1.47	2.0	41	25	100
Crimson clover	20.0	1.69	2.5	54	24	112

to 1.48%, while the same crops grown on a soil with a higher organic matter level increased from 2.52% to 2.70%. This survey also showed that soils containing more than 2.5% organic matter were obtained only for fields where lespedeza had been growing continuously, indicating that levels higher than 2.5% are rather difficult to maintain under ordinary farming practices.

The data in Table 2 further exemplify this point as with ordinary cotton farming where commercial fertilizers are used exclusively the soil contained 1.23% organic matter, while the cumulative effect from 12 annual applications of 8 tons of manure gave an increase up to 1.76%, while the use of rye and vetch as a green manure for the same period maintained a total content of 1.72%. Only slightly higher percentages were obtained by the combination treatment of 8 tons of manure along with the rye and vetch cover crop.

TABLE 2.—*Yields of seed cotton, organic matter content, and available soil nutrients in Cecil sandy loam soil as influenced by incorporation of manure and green manure.*

Treatment	Average yield of seed cotton, lbs. per acre*	Organic matter content, %	Available soil nutrients determined by laboratory methods			
			NO_3N		P, p.p.m.	K, p.p.m.
			Initial, p.p.m.	After incubation, p.p.m.		
Check	1,298	1.23	1.5	32	34	64
8 tons manure	1,626	1.76	12.0	51	60	117
Rye and vetch turned under as a green manure	1,553	1.72	5.5	49	38	107
8 tons manure plus rye and vetch turned under as a green manure	1,791	1.87	7.5	59	52	120

*Yields as reported by Patrick (7).

Results of recent studies dealing with different methods of supplying organic matter are shown in Tables 3 and 4. These results are indicative of the effectiveness of the treatments as only three annual applications were supplied before the analyses were made. The original soils contained a fairly high level of organic matter of approximately 2%. Incorporating 4 tons of crimson clover increased the organic matter to 2.52%, while the same amount applied on the surface as a mulch gave approximately the same percentage, 2.54. However, the mulch treatment gave a decidedly darker color to the soil which may have been due to humic constituents of the organic matter leaching into the soil. The effectiveness of growing summer legumes and allowing the entire plant material to accumulate on the soil as a natural mulch is shown in Table 4. A comparison of this accumulation treatment with the incorporation of hays shows that

soils receiving the 5-ton crimson clover incorporated treatment increased in organic matter from 2.05% to 2.89%, whereas the accumulated lespedeza residue treatment increased from 2.05% to 3.74%. Thus, these studies show that the organic matter content of soils in the Southeast can be increased by using summer and winter legumes exclusively as green manure crops, but the maintenance of the higher organic matter levels will be an economic rather than an agronomic problem.

TABLE 3.—*The effect of mulching and of incorporating crimson clover in Cecil sandy loam on organic matter, nitrate nitrogen, available phosphorus, and potassium contents.**

Treatment	Sorghum yields, grams per pot	Organic matter content, %	Available soil nutrients determined by laboratory methods: NO_3N after the addition of crimson clover, Outset, p.p.m.	56 days, p.p.m.	120 days, p.p.m.	P, p.p.m.	K, p.p.m.
Check (no plant material applied)	2.3	1.75	7	16	41	16	54
4 tons crimson clover incorporated	4.5	2.52	8	16	82	21	145
4 tons crimson clover applied as a mulch	4.3	2.54	12	18	79	26	142

*Experiment in cooperation with S. C. S. Res. SC. R-1.

TABLE 4.—*Fertility level of Cecil sandy loam soil as influenced by the incorporation of crimson clover and the accumulation of lespedeza residues.*

Treatment	Sorghum yields, grams per pot	Organic matter content, %	Available soil nutrients determined by laboratory methods: NO_3N, April 1941, p.p.m.	NO_3N, Dec. 1941, p.p.m.	P, p.p.m.	K, p.p.m.
Check	2.1	2.05	9	20	16	48
5 tons crimson clover incorporated	5.0	2.89	12	54	27	188
Lespedeza (residues accumulated to form a natural mulch)	4.5	3.74	5	10	30	136

SOIL NUTRIENTS AND ORGANIC MATTER CONTENT

The addition of leguminous plant material as hays and plant residues to the surface soil supply nutrients in proportion to the composition of the material. In all cases, if soils have been properly inoculated,

total nitrogen should be increased, while the availability of the phosphorus and potash should be favored by bringing these elements into the feeding zones of the plants. Crimson clover hay applied at the rate of 5 tons per acre adds 105 pounds of nitrogen, 20 pounds of phosphorus, 125 of potassium, and 120 pounds of calcium. Lespedeza hay at the same rate of application adds 102 pounds of nitrogen, 18 pounds of phosphorus, 72 pounds of potassium, and 102 pounds of calcium. However, the complex plant constituents, namely, nitrogen and phosphorus compounds, will be available for absorption only after the materials have been mineralized by the soil organisms which requires approximately 30 to 90 days after their addition.

The available soil nutrients as determined by laboratory methods are given in Tables 1, 2, 3, and 4. Unfortunately, the initial soil samples for determining nitrate nitrogen, as shown in Table 1, were taken during the early spring months and little differences were obtained between the check soil and the soil where legumes had been incorporated. However, when these soils were incubated at optimum conditions for a period of 90 days, the nitrate nitrogen produced by the lespedeza, vetch, and crimson clover treatments was 50, 41, and 54 p.p.m., respectively, while the check soil developed only 17 p.p.m. The nitrate nitrogen content for the soil of the continuous cotton experiment (Table 2) was relatively low, but some differences prevailed. The soil samples were not secured when nitrates were at their maximum development, but during incubation these soils produced significant increases. The soil from the commercial fertilizer plat contained 32 p.p.m. of nitrate nitrogen, while the manure, vetch, and combination treatments gave 51, 49, and 59 p.p.m., respectively.

The nitrate development on the check, crimson clover incorporated, and lespedeza accumulation plots was obtained by incubating these respective soils for a period of 90 days in the greenhouse. These data are given in Table 5 and show that the check soil maintained a nitrate nitrogen content between 20 and 26 p.p.m., while the crimson clover which had 54 p.p.m. of nitrate nitrogen at the outset of incubation period increased to 78 p.p.m. during the 90-day period. Lespedeza gave considerable variation. Beginning at 10 p.p.m., the nitrates declined to 2 p.p.m. at 15 days, while at 30 days they had increased to 25 p.p.m. The nitrates then continued to increase up to 120 days when the nitrate nitrogen content reached 61 p.p.m. These nitrification studies show that if lespedeza is used in this manner it should be plowed under at least 30 days before seeding the succeeding crop.

TABLE 5.—*The development of nitrate nitrogen in Cecil sandy loam from incorporated crimson clover and accumulated lespedeza residues.*

Treatment	P.p.m. of NO_3N during incubation				
	Outset	15 days	30 days	60 days	90 days
Check (no organic matter)......	20	20	19	20	26
Incorporated crimson clover....	54	54	46	50	78
Accumulated lespedeza residues	10	2	25	45	61

In order to follow the effect of organic matter additions under field conditions on the soil nutrient supply, the experiments reported in Tables 3 and 4 were initiated in 1939. The results to date show that crimson clover applied either as a mulch or incorporated with the soil increased nitrates from approximately 8 to 16 p.p.m. during the first 56 days following such applications. No significant differences occurred in nitrates during the first 56 days between the check and organic matter treated soils, but after this period nitrification was most active and maximum production was reached at 120 days. At this time the check soil contained 41 p.p.m. while the mulched soil increased to 79 p.p.m. and the incorporated treatment produced 82 p.p.m.

Further comparison in Table 4 shows that growing the legume *in situ* and allowing the entire plant to accumulate as a mulch has reduced the nitrate content to a low amount. The maximum field concentration of 10 p.p.m. of nitrates indicates that nitrogen was contained largely as complex plant constituents and nitrification processes are retarded until the plant becomes incorporated with the soil. Thus, the formation of natural mulches by plants is a good conservation practice both from the standpoint of controlling soil and water losses during the open winter months and for holding the nitrogen largely in complex form during this period.

The available phosphorus content for the soils of this investigation shows that organic matter additions had increased acid-soluble phosphorus. The soil samples selected in the South Tyger River Project area near Spartanburg, S. C. (Table 1), show that nonlegume soils had approximately 19 p.p.m. of acid-soluble phosphorus, while soils supplied with organic matter from lespedeza, vetch, or crimson clover gave 25 p.p.m. of available phosphorus. Other experiments also show small fluctuations in favor of the legume-treated soils, giving 16 p.p.m. for check soils, while 21 and 26 p.p.m. of phosphorus were obtained for the incorporated crimson clover and mulched treatments. The lespedeza accumulated plot contained 30 p.p.m. of acid-soluble phosphorus whereas the phosphorus released by the 8 tons of manure was almost twice that of the complete fertilizer plat. In decomposition processes considerable mobilization of phosphorus occurs. Lockett (4) has shown that in the decomposition of mature clover that inorganic phosphorus was immobilized as a decrease in this form of phosphorus occurred during an 80-day incubation period. Apparently in the multiplication of soil organisms the inorganic phosphates are assimilated, causing a temporary decrease of inorganic phsophates until they are again liberated through mineralization.

Data on exchangeable potassium content of the soils are also presented and show that the average of nonlegume soils collected in the South Tyger River Project area contained 64 p.p.m., while 100 to 112 p.p.m. of potassium were found in those soils where legumes had been turned under as green manure. Significant differences in potassium were found in the soil of the Clemson organic matter experiments (Tables 3 and 4). The check soils contained approximately 50 p.p.m., while incorporating 4 tons of clover increased the replaceable potas-

sium content to 145 p.p.m. and the clover applied as a mulch produced 142 p.p.m. The 5-ton crimson clover incorporated treatment increased the potassium to 188 p.p.m., while the lespedeza accumulation plot contained 136 p.p.m. The potassium absorbed by the colloidal complex of the soil undoubtedly was derived from the potash released by the organic matter. Tam and Magistad (9) have also concluded that an increased potash content of soils from decomposing pineapple trash was directly associated with the potassium content of the added plant material.

These data indicate that organic matter either added to or grown on soils increases the available potassium of the surface soil and this is partially responsible for the increased yields secured.

CROP YIELDS AND ORGANIC MATTER ADDITIONS

Considerable evidence has been presented to show that green manures are beneficial for increasing yields. Most of the data secured for southern soils strongly support the contention that the addition of vetch, Austrian peas, crimson clover, and lespedeza are beneficial because of the increased nitrate nitrogen supply of the soil. In Alabama (2), the average yields of seed cotton were increased from 349 to 756 pounds through the use of a vetch green manure crop. In Georgia (3), 951 pounds were secured from 100 pounds of nitrate of soda, while hairy vetch turned under produced 1,044 pounds. Data by Patrick (7), given in Table 2, show that the complete fertilizer treatment yielded 1,298 pounds of seed cotton in comparison with 1,553 pounds from the rye and vetch green manure treatment, but when these treatments were reinforced with 100 pounds of nitrate of soda, 1,652 pounds were secured from the former treatment and 1,698 pounds from the latter treatment. Paden (6) reported increases for these various sources of nitrogen and obtained 2,138 pounds of seed cotton for nitrate of soda, 2,394 pounds for Austrian winter peas, and 2,610 pounds for rye and vetch. These yields are considered significant since only 1,449 pounds were secured from the no-nitrogen treatment.

Pot experiments reported in Tables 1, 3, and 4 give further evidence that the incorporation of organic matter with the soil is an effective practice for the South. Sorghum yields increased from 2.3 grams per pot to 4.5 grams from the addition of leguminous plant material (Fig. 1), while rye yields increased from 7.5 grams to 15, 19.9, and 20 grams per pot where lespedeza, vetch, and crimson clover were the sources of organic matter, respectively. Also, the data secured in this investigation suggest that green manuring is not only beneficial because it increases the nitrate-nitrogen content, but also because it makes phosphorus and potassium more available for crop production.

SUMMARY

Studies dealing with the addition of leguminous plant materials to soil as green manures, hay mulches, and accumulated residues were made to determine the effects of these various methods of application on the organic matter content of soils, the available soil nutrient

supply, and yields of succeeding crops. The results obtained warrant the following conclusions:

The average organic matter content of the cultivated soils in the Piedmont section of South Carolina is approximately 1%, while plant materials supplied by growing lespedeza, vetch, and crimson clover have raised the percentage of organic matter to 1.5. Only where lespedeza is grown continuously on the same soil for a number of years from 2.5 to 2.7% have been attained, indicating that amounts as high as 2.7% would be difficult to maintain under ordinary farming practices.

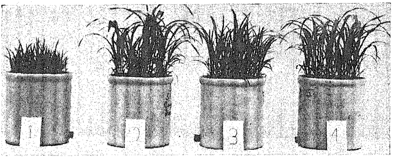


FIG. 1.—Growth of sorghum as influenced by organic matter additions. Treatments 1 to 4 are check, crimson clover incorporated, crimson clover mulched, and accumulated lespedeza residues, respectively. The respective yields were 2.3, 5.0, 4.3, and 4.5 grams.

Analyses for nitrate nitrogen show that under field conditions check soils produced a maximum of 41 p.p.m., while 4 tons of crimson clover applied either as a mulch on the surface, or incorporated with the soil accumulated 80 p.p.m. The lespedeza accumulated residues treatment maintained approximately 10 p.p.m. and remained at this level until these residues were incorporated, when 61 p.p.m. of nitrate nitrogen developed after 120 days of incubation.

The acid-soluble phosphorus tests showed that soils from nonlegume areas contained 16 p.p.m. of available phosphorus, whereas 25 to 30 p.p.m. were found in the soil receiving the leguminous plant material.

The replaceable potassium content varied with treatment, giving 48 to 64 p.p.m. for nonlegume plats, while the legume-treated soils contained from 136 to 188 p.p.m.

Significant yield differences were secured for sorghum and rye from the addition of plant materials to the soil over that produced on the adjacent soil receiving only commercial fertilizer. These results suggest that leguminous plant additions are beneficial for soil improvement not only for the nitrogen supplied, but also because they render phosphorus and potassium more available.

LITERATURE CITED

1. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and Tentative Methods of Analyses. Ed. 4. 1935.
2. BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. Experiments with legumes in Alabama. Ala. Agr. Exp. Sta. Bul. 232. 1930.
3. HALE, G. A. A comparison of winter legume green manure and nitrate of soda fertilizing cotton. Jour. Amer. Soc. Agron., 28:156-159. 1936.
4. LOCKETT, J. L. Nitrogen and phosphorus changes in the decomposition of rye and clover at different growth stages. Soil Sci., 45:13-24. 1938.
5. MOSER, FRANK. The influence of cropping practices on some physical and chemical properties of soil. Soil Sci., 48:421-431. 1939.
6. PADEN, W. R. Responses from various sources of nitrogen fertilizer. S. C. Agr. Exp. Sta. Bul. 309. 1937.
7. PATRICK, C. S. Soil management studies. S. C. Agr. Exp. Sta. Ann. Rpt., 53:93-95. 1940.
8. PEELE, T. C., and MOSER, F. Soil conservation investigations. S. C. Agr. Exp. Sta. Ann. Rpt., 52:37-42. 1939.
9. TAM, R. H., and MAGISTAD, O. C. Chemical changes during decomposition of pineapple trash under field conditions. Soil Sci., 41:315-327. 1936.
10. TRUOG, E. E. The determination of ready available phosphorus in soils. Jour. Amer. Soc. Agron., 22:814-882. 1930.
11. VOLK, N. J., and TRUOG, E. E. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26:537-546. 1934.

PARENTAL CORN INBREDS: HAND POLLINATION METHODS AND COST STUDIES[1]

J. W. THAYER, JR., AND E. E. DOWN[2]

THIS paper reports 1941 yield data, time records, and costs pertinent to the production of 656 pounds of parental inbred seed corn by hand pollination. There also is presented a comparison of the efficiency of the "tassel bagging" method (2)[3] as contrasted with the "bottle" method (2, 3) for hand pollination. Cost and pollination studies have also been reported by Johnson and Hayes (4) and by Richey (5).

MATERIALS AND METHODS

In 1941, the Michigan Experiment Station replaced isolated plot increases of parental inbred corns with controlled pollination plots as suggested by Borgeson and Hayes (1). To produce 1942 seed, 21 parental inbred strains (Table 1), were planted on the college farm in plots which varied in size according to the production required. Plantings of all strains were made at two dates, 10 days apart, to minimize the danger of having all pollinations of any one strain occurring within a limited unfavorable weather period and to spread the work of pollinating.

Pollinating was limited to selfing and the work was done by both the tassel bagging and bottle methods. At harvest all selfed ears were picked and taken to the laboratory where, after drying, they were sorted and shelled.

During the season a record was kept of man hours and materials used in pollinating, harvesting, sorting, and shelling. Time was recorded as total elapsed man hours on the job and no records were kept for short test periods. Regular 3×7 inch glassine shoot bags ($1.90 per M) and special water-proof adhesive No. 12 brown kraft anti-pollination bags ($3.05 per M) were used. Two gross 2-ounce, flint glass bottles (2 cents each) fitted with a 6-inch length of No. 22 bare copper magnet wire were available for the bottle pollinating work.

Four inbred strains CC 1, CC 5, CC 7, and WF 9 were selected for testing the efficiency of the tassel bagging against the bottle method for hand pollinating. In each plot selfings were made by the tassel bagging method on the even-numbered rows and by the bottle method on the odd-numbered rows.

RESULTS AND DISCUSSION

The productivity of each strain is recorded as the average number of seeds obtained per pollination, Table 1, column 5. It is not surprising that this figure varies from a high of 298 to a low of 44, because it is dependent upon the inherent productive ability of the strain and the success one has in obtaining fertilization by hand pollination. The latter will vary greatly within a strain but the "percentage of pollinations shelled," Table 1, column 4, indicates that success in obtaining fertilization also varies considerably from strain to strain. This variation is too great, from a high of 83.8% to

[1]Contribution from the Farm Crops Department of Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 579 (new series). Received for publication April 11, 1942.

[2]Research Assistant and Research Professor, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 724.

a low of 34.3%, to be ascribed to chance alone. It does not appear, however, to be due to changing weather conditions, but must be due to inherent differences within the strains themselves because strains which were pollinated during the same period differed widely in this respect.

TABLE 1.—*Pollination data, seed yields, and cost per 1,000 seeds for 21 parental inbred strains of corn grown in 1941.*

Strain	No. of pollinations	No. of ears shelled*	Percentage of pollinations shelled	Average No. of seeds per pollination	Average No. seeds per pound	Lbs. of seed produced	Cost per 1,000 seeds†
CC1...	1,159	937	80.8	205	3,155	75.6	19.7
CC4.....	566	352	62.2	234	2,585	51.4	17.3
CC5.....	561	398	70.9	298	3,293	50.9	13.6
CC6.....	163	96	58.9	84	1,563	8.8	48.0
CC7.....	435	291	66.9	160	2,686	25.9	25.3
CC8.....	2,006	1,227	61.2	101	1,847	109.9	40.1
Ill A.....	523	358	68.4	130	2,566	30.0	31.2
Minn 16..	198	68	34.3	44	1,704	3.5	91.0
Minn 20..	234	104	44.4	57	2,277	7.9	70.5
W. F. 9...	327	160	48.9	94	2,761	11.2	42.8
US 153...	540	429	79.4	170	1,993	46.3	23.8
MS 9.....	538	397	73.8	109	2,535	23.1	37.2
MS 10....	222	163	73.4	230	1,911	26.7	17.6
MS 11....	253	207	81.8	187	2,211	21.4	21.7
MS 1459.	261	101	38.7	89	1,997	12.6	45.5
Ind Fe...	114	95	83.3	173	2,117	9.3	23.4
51 A.....	256	155	60.5	86	1,822	12.1	47.1
CC24....	340	305	89.7	196	1,977	33.7	20.7
CC25....	531	409	77.0	120	1,836	34.7	33.8
CC27....	272	228	83.8	204	2,329	23.9	19.9
40B......	538	311	57.8	105	15,93	36.7	38.6
Total....	10,037	6,791				655.6	
Average..			67.6	146.5			34.7

*Ears with relatively few kernels as compared with the average for the strain, ears showing appreciable rot or mold, and ears considered inferior for any other reason were discarded. Poor pollination was the chief reason for discarding ears.
†Estimated by using cost of 4.05 cents per pollination as a base. (See Table 2.)

Approximately 4 minutes per pollination (Table 2), or only 15 pollinations per hour, may be considered as a very slow rate by many familiar with corn pollinating work. It should be remembered, however, that this is an average rate for the entire season during which 10,037 self pollinations were made. It includes all the operations connected with pollinating throughout the season and not merely the number of pollinations that a man can make in a rush or test period during the height of the season.

When material and labor (45 cents per hour) costs (Table 2) for the season were totaled, the average cost per pollinated ear was 4.05 cents. The cost of production per thousand seeds for the different strains, Table 1, column 7, varied from a high of 91.0 cents to a low of 13.6 cents with an average cost of 34.7 cents.

TABLE 2.—*Time and cost records secured during production of parental inbred corn seed in season of 1941.*

Job	Hours of labor	Minutes of labor per pollination	Labor cost per pollination
Pollinating	655	3.92	$0.0294
Harvesting and shelling	119	0.71	0.0053
Total	774	4.63	$0.0347
Total labor cost: 774 hours @ 45c			$348.30
Total material cost: Bags, clips, tags, etc.			58.20
Total cost of pollination			$406.50

Total cost per pollination $\frac{\$406.50}{10{,}037} = 4.05$ cents

Total cost per pound of seed $\frac{\$406.50}{655.6} = 62.0$ cents

TASSEL BAGGING VS. BOTTLE METHOD

After the workers became familiar with the operations connected with the use of bottles, there was no difference between the two methods from the standpoint of time consumed. Placing of bud sacks is the same for both methods. With the bottle method, pollination is completed in one operation, whereas when no bottle is used the tassel bag must be put on one day and pollination completed sometime later.

The data (Table 3) indicate that the advantages to be derived from the use of bottles are somewhat dependent upon the characteristics of the inbred strain. The seed yield of CC1, a strain which produced abundant pollen, was not increased by the use of bottles. However, CC5, CC7, and WF9 responded very favorably to their use. In these

TABLE 3.—*Production and cost data from pollination tests on strains CC1, CC5, CC7, and WF9 using the tassel bagging and bottle methods during the season of 1941.*

Strain	No. of pollinations	No. of ears shelled	Percentage of pollinations shelled	No. of seeds per pollinations	No. seeds per pound	Lbs. of seed produced	Cost per 1,000 seeds†
CC1	521	423	81.2	211	3,155	34.9	19.2
CC1*	638	514	80.6	201	3,155	40.7	20.1
CC5	389	245	63.0	267	3,293	31.8	15.2
CC5*	172	153	88.9	365	3,293	19.1	11.1
CC7	232	134	57.8	135	2,686	11.7	30.0
CC7*	203	157	77.3	188	2,686	14.2	21.5
WF9	221	77	34.8	81	2,761	6.4	50.0
WF9*	106	83	78.3	124	2,761	4.8	32.7

*Bottle method.
†Estimated by using cost of 4.05 cents per pollination as a base. (See Table 2.)

latter strains pollen was not particularly abundant and in many instances was mostly shed before silks were available on the ear shoot. The substantial increases in percentage of pollinations acceptable for use, together with the higher seed yield per pollination (Table 3), indicate the value of using bottles with these inbreds.

With the four strains under test, it cost on the average 28.6 cents per 1,000 seeds to produce seed by the tassel bagging method and 21.3 cents with bottles,[4] a saving of 25.5% in favor of the bottle method. Advantages, other than monetary savings, should also be recognized for the "bottle" method. Pollinations may be made at any time when it is not raining and delays due to waiting for tassel bags to dry are avoided. Tassels weakened by corn borer are not broken and lost because no tassel bag is necessary.

The above undoubtedly still leaves the question unsettled as to whether or not the bottle method should be used generally in preference to the tassel bagging method. However, taking into consideration the facts that (a) bottle cost is small, (b) the bottle method is rapid and no more costly than the tassel bagging method, (c) the bottle method has several advantages over the tassel bagging method, (d) more seed may be secured per pollination by using bottles, and (e) the cost of producing 1,000 seeds is less when bottles are used, it appears that the bottle method has much in its favor.

SUMMARY

During the 1941 season, yield data and time and cost records covering man hours spent in pollinating, harvesting, sorting, and shelling were kept for the production by hand pollination of seed for 21 parental corn inbreds.

The percentage of attempted pollinations acceptable for seed averaged 67.6 for all strains and ranged from a high of 83.3 to a low of 34.3 for individual strains. For the 10,037 attempted pollinations, the average yield per pollination per strain ranged from a low of 44 seeds to a high of 298 seeds and the average for all strains was 146.5 seeds.

At the end of the season, the records showed that the average pollination required 3.92 minutes of man labor in the field and harvesting, sorting, and shelling required an additional 0.71 minute. With labor at 45 cents per hour, the cost per pollination, including materials, was approximately 4 cents.

The cost of producing parental inbred seed corn varied between strains from a high of 91.0 cents per 1,000 seeds to a low of 13.6 cents. The average cost per 1,000 seeds for the 656 pounds of seed produced was 34.7 cents.

On four strains, pollinations were made by the tassel bagging and bottle methods. One strain produced equally well with both methods, but the other three strains produced materially more when bottles were used. The cost of production for the four strains was 21.3 cents

[4]No charge was added to this cost for bottles. If bottle life is taken as 5 years and the cost per bottle including wire and labor of attaching as 4 cents, it is estimated on the basis of the work done that the bottle cost would be approximately 0.024 cents per 1,000 seeds.

per 1,000 seeds when bottles were used and 28.6 cents with the tassel bagging method, an average saving of 25.5% in favor of the bottle method.

LITERATURE CITED

1. BORGESON, CARL, and HAYES, H. K. The Minnesota method of seed increases and seed registration for hybrid corn. Jour. Amer. Soc. Agron., 33:70–74. 1941.
2. JENKINS, M. T. Corn improvement; Several methods used to control pollination. U. S. D. A. Yearbook, 1936:473–475. 1936.
3. ————. New method of self-pollinating corn. Jour. Heredity, 14:41–44. 1923.
4. JOHNSON, I. J., and HAYES, H. K. A comparison of hand and wind pollination in making F_1 crosses between inbred lines of corn. Jour. Amer. Soc. Agron., 24:85–90. 1932.
5. RICHEY, F. D. The intensive production of single crosses between selfed lines of corn for double crossing. Jour. Amer. Soc. Agron., 20:942–946. 1928.

EFFECT OF DISEASES UPON SURVIVAL OF WHITE CLOVER, *TRIFOLIUM REPENS* L., IN ALABAMA[1]

H. R. ALBRECHT[2]

WHITE clover, *Trifolium repens* L., although generally classified as a perennial legume, behaves largely as a winter annual in Alabama. It has been commonly accepted that white clover frequently fails in the South due to its inability to withstand the extremely hot weather prevalent during the summer. No attempt is made here to disprove this belief, but evidence is presented which suggests that certain diseases are responsible for the disappearance during the summer of much of the white clover in Alabama pastures.

METHODS

This study of the effect of diseases on white clover was begun during the summer of 1940 when it was observed that a number of the 1,700 individual plant selections growing in the breeding nursery were becoming infected with several diseases. Notes were taken on the effect of the diseases on only 750 of the plants growing in one section of the field. The extent of injury each disease caused to each plant and the rapidity of recovery of survivors from disease attack were noted.

Plants which escaped attack by one or several diseases in 1940 were propagated vegetatively in another section of the same field so that they could be tested again in 1941 for possible resistance to disease. No plants were artificially inoculated with any organism.

Surveys were made of pastures in all sections of the state in 1940 and in 1941 to determine whether the diseases which were common in the nursery at Auburn were also prevalent in farmers' pastures. While there was no difficulty encountered in recognizing the diseases that occurred on white clover growing in these pastures, it was often impossible to judge the extent of injury which the diseases caused. In a number of cases, however, certain diseases were found to be so prevalent that there is little doubt that stands of white clover growing in pastures were substantially reduced due to disease attack.

RESULTS AND DISCUSSION

Diseases may attack white clover in Alabama in early spring, but they appear to cause their greatest injury to the plant late in June and in July after the major seed crop has been matured. Ten organisms have been recognized[3] as attacking white clover in Alabama:

1. *Sclerotium rolfsii* Sacc.
2. *Heterodera radicicola* (Greef.) Muell.
3. *Stagonospora meliloti* (Lasch.) Petr.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication April 23, 1942.

[2]Associate Agronomist.

[3]The organisms discussed in this paper were identified by Doctor J. L. Seal, Head, Department of Botany and Plant Pathology, Alabama Agricultural Experiment Station.

4. *Cercospora* sp.
5. *Polythrincium trifolii* Kunze
6. *Botrytis* sp.
7. *Sclerotinia trifoliorum* Eriks.
8. *Bacillus lathyri* Manns and Taub.
9. *Colletotrichum trifolii* S. M. Bain
10. *Fusarium* sp.

Several organisms, of course, can attack white clover at the same time. Of the 750 plants studied in 1940, only 24 were attacked by a single pathogen, 130 were attacked by two, 275 by three, 282 by four, and 39 by five (Table 1). Eight plants were severely diseased by as many as three organisms. The extent of destruction of the plants was rather closely associated with the severity of disease attack. It should be stated that the most extensively destroyed plants were so severely diseased with southern blight (*S. rolfsii* Sacc.) as to mask the possible symptoms of attack by other pathogens (Fig. 1).

TABLE 1.—*Disease prevalence among white clover plants in the nursery, Auburn, Ala., Aug. 1, 1940.*

Extent of tissue killed, area of plant	Number of plants observed	Number of plants having number of diseases shown					Number of plants having number of severe diseases shown			
		1	2	3	4	5	0	1	2	3
None	236	9	55	91	70	11	126	88*	18*	4*
Up to ¼	237	11	41	73	93	19	94	101	39	3
¼–½	145	0	16	52	71	6	30	88	26	1
½–¾	89	3	10	44	30	2	10	64	15	0
¾–all	43	1	8	15	18	1	2	39	2	0
Total	750	24	130	275	282	39	262	380	100	8

*These plants either showed numerous small lesions as a result of disease attack or mycelium of certain organisms was found in abundance. No leaves or stems had been entirely killed.

The southern blight organism, *S. rolfsii*, has proved to be the most destructive of the several organisms attacking white clover that were studied (Fig. 2). It attacked severely 481 of the 750 lines under observation in 1940 (Table 2) and 202 of the 277 lines studied in 1942. It is primarily a root and stem disease. Ladino clover, and others of similar type, seem particularly susceptible to attack by the organism.

TABLE 2.—*Prevalence and severity of five plant pathogens in a population of 750 white clover plants, Aug. 1, 1940, Auburn, Ala.*

Organism	Number of plants infected	Number of plants severely diseased
Sclerotium rolfsii	672	481
Stagonospora meliloti	685	105
Botrytis sp.	586	60
Colletotrichum trifolii	114	15
Sclerotinia trifoliorum	411	—

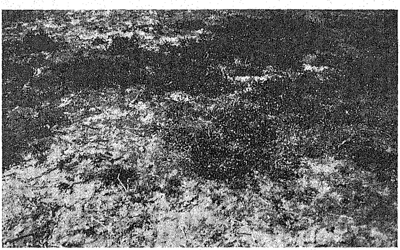


FIG. 1.—Destruction of white clover by disease on rod square plot, Auburn, Ala., summer of 1941. *Sclerotium rolfsii* Sacc. was the predominant plant pathogen attacking these plants.

Few such plants under observation at Auburn have survived attack by this disease. The claim is not made, however, that there exists a relation between plant type and resistance to southern blight, because plants of all growth types have been severely infected by the causal organism.

S. rolfsii has been found to attack white clover in pastures in all sections of Alabama (Table 3). It has not, however, been found abundant in pastures which have been heavily overgrazed or in

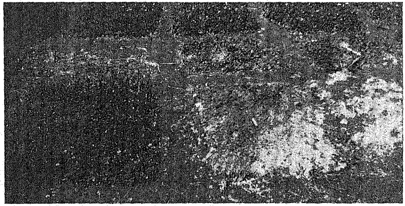


FIG. 2.—Left front, a disease-free white clover plant surrounded by plants severely diseased by *S. rolfsii* in 1940. This plant also displayed high resistance to this organism in 1941.

sparsely vegetated pastures. The same general observation has been made in the case of other diseases under study, except root knot and Cercospora leaf spot.

TABLE 3.—*Prevalence of severe diseases in 25 Alabama pastures in the summer of 1941.*

Section of state	Number of pastures severely attacked by			
	Stagonospora meliloti	*Cercospora* sp.	*Sclerotium rolfsii*	*Heterodera radicicola*
Southern.........	5	1	3	4
Central..........	8	7	3	3
Northern.........	2	6	2	—

There is a possibility that some resistance to attack by *S. rolfsii* occurs in white clover (Fig. 2). A number of strains, 38, which proved to be free of the disease at Auburn in 1940 also remained free of infection in 1941. Some of these strains have also been tested in northern and in southern Alabama, and there too they have shown high resistance to southern blight. At every station, these strains have been surrounded by highly or moderately diseased strains.

Root knot, *Heterodera radicicola* (Greef.) Muell., was responsible for the elimination of many of the white clover strains growing at Auburn in 1940. In one field 100 out of 343 strains were heavily infested with nematodes in mid-August and most of these had perished by mid-September. Nematode galls were noted on many white clover plants growing in seven pastures on sandy soils of central and southern Alabama. This disease evidently presents no problem on heavy soils.

Stagonospora meliloti (Lasch.) Petr. and *Cercospora* sp. appear to cause the most widely distributed leaf spot diseases of white clover in Alabama. They have been noted to occur in pastures in all sections of the state (Table 3). *S. meliloti* occurs most commonly in May through June, whereas *Cercospora* sp., in 1941 at least, was the predominant disease of white clover during the months of August and September. No resistance to Cercospora leaf spot has been apparent in the white clover strains tested to date, but there is some difference among the strains as to extent of injury due to attack by *S. meliloti*.

Few of the other diseases studied were found to attack white clover severely in Alabama pastures. Some, like those caused by *Polythrincium trifolii* Kunze, *Botrytis* sp., *Sclerotinia trifoliorum* Eriks., and *Bacillus lathyri* Manns and Taub., were noted to be widely distributed in Alabama, but the extent of the injury they caused to white clover growing in pastures was difficult to judge. Individual plants severely diseased by these organisms were found.

White clover must depend largely upon voluntary reseeding to maintain itself in Alabama pastures. The seedlings begin to appear in number in September or October, but their development is frequently arrested due to fall droughts and prolonged periods of low temperature. Consequently, they furnish little grazing for livestock until late in March or in April.

The white clover strains tested at Auburn and at the Tennessee Valley and Gulf Coast Sub-stations which either escaped severe disease injury or were resistant to disease have characteristically produced abundant vegetative growth in the fall and winter (Fig. 3). Severely diseased survivors were slow to begin their growth in the fall and they did not generally reach their period of heavy vegetative growth until May or later as they approached their height of bloom. This delayed fall and winter growth of severely diseased white clover permitted winter weeds to establish themselves strongly in all plots and row tests in which extensive stand reductions due to disease occurred.

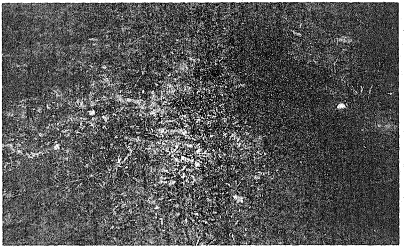


FIG. 3.—Early winter growth of white clover. *Left*, strain severely diseased in summer of 1941. *Right*, not severely diseased in summer of 1941.

SUMMARY

Studies of diseases of white clover in pastures and in strain tests at several locations in Alabama suggest that diseases are responsible for the failure of much of the white clover during the summer.

Thus far, 10 diseases have been recognized on white clover in Alabama. Southern blight, *S. rolfsii* Sacc., has proved to be the most destructive of the diseases studied to date. Leaf spots caused by *Stagonospora meliloti* (Lasch.) Petr. and *Cercospora* sp., and root knot, *Heterodera radicicola* (Greef.) Muell., were also highly destructive to white clover growing in Alabama pastures. The tests indicated that some degree of resistance to most of the diseases occurs.

Diseases became most destructive to white clover after the main seed crop had matured, after mid-June.

The white clover in overgrazed or sparsely vegetated pastures was not generally attacked severely by disease. Diseases have been found to occur abundantly only in pastures characterized by heavy growth.

The exceptions to this generalization were root knot and Cercospora leaf spot, which occurred usually in late summer. Observations suggested that disease prevalence may actually have been a consequence of good pasture management.

Heavy growths of winter weeds became established on all plots at Auburn which had suffered extensive stand reductions due to the prevalence of disease.

THE PRODUCTION OF GREY SPECK OF OATS IN PURIFIED SAND CULTURES[1]

R. H. HAGEMAN, J. S. MCHARGUE, G. DONALD SHERMAN, AND E. S. HODGE[2]

GREY speck, a physiological breakdown of the leaf tissue, has been recognized as the manganese-deficiency symptom of oats. Sjollema and Hudvig (10)[3] in 1909 prevented the development of the condition by applying manganese sulfate to the soil. Since their discovery, grey speck of oats has been recognized as the malnutrition symptom indicating an inadequate supply of available manganese in the soils of Wales (1), Netherlands (2, 11), Australia (5, 7), and the United States (9).

The authors do not find that grey speck has been reported on oats grown in cultures presumably devoid of manganese. This fact indicates that either the condition is not due to lack of manganese or the culture plants derive sufficient manganese from the distilled water, chemicals, and containers used in the experiment.

To determine if grey speck would develop in oats grown in the absence of manganese, an experiment of purified sand cultures was made in which all traces of manganese were removed from the chemicals, distilled water, and sand. Another experiment was set up in which the chemicals were not purified and to which no manganese salt was added. All manganese obtained by the plants in this culture would be due to impurities in the cultures used. The "three-salt solution" was used for the basic nutrition in this study (4).

METHOD OF PURIFICATION

Distilled water.—The distilled water was purified by distillation in a quartz condenser described by McHargue and Offutt (6). Spectrographic analysis showed that manganese had been eliminated from the water.

Chemicals.—The method of Stout and Arnon (13) was used, which is a modification of the procedure described by Steinberg (12). The procedure depends on the adsorption of the minor elements on an alkaline calcium carbonate-potassium phosphate complex when added to each separate molar nutrient solution. The molar solution plus the adsorbent complex is autoclaved and filtered. The filtrate of the molar salt solution after the autoclave treatment was put into a large separatory funnel and 1.0 ml of a 0.1% solution of dithizone and 5.0 ml of redistilled chloroform added and the funnel shaken vigorously for 5 minutes or longer. The chloroform layer was allowed to settle and then removed. This process was repeated until the color of the green chloroform layer remained unchanged.

[1]Contribution from the Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication April 25, 1942.

[2]Assistant Chemist, Head of Department, and formerly Assistant Chemists, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 734.

The dithizone extraction removes zinc, copper, lead, nickel, cobalt, mercury, cadmium, thallium, and bismuth from the solution. Spectrographic analysis revealed that manganese was removed from the basic nutrient solution.

Iron compounds usually carry a considerable quantity of manganese as a contamination. Manganese was removed by precipitation with pyridine as described by Ray (8). The final precipitation was made with ammonium hydroxide to remove traces of pyridine.

Containers.—Glazed 2-gallon jars were used. They were washed with strong hydrochloric acid and thoroughly digested and rinsed with distilled water.

Quartz sand.—This was digested with hot hydrochloric and nitric acids and washed with distilled water until no test was obtained for chloride.

EXPERIMENTAL WORK

The jars were filled with acid-washed sand and the following treatments applied as parts per million of nutrient solution:

1. Majors (4) + A-Z solution (3).
2. Majors + 0.5 p.p.m. B, 0.1 p.p.m. Zn, 0.1 p.p.m. Cu; chemicals not purified.
3. Majors + 0.5 p.p.m. B, 0.1 p.p.m. Zn, 0.1 p.p.m. Cu; chemicals purified.
4. Majors + 0.5 p.p.m. B, 0.1 p.p.m. Zn, 0.1 p.p.m. Cu, 2.0 p.p.m. Mn.
5. Majors + 0.5 p.p.m. B, 0.1 p.p.m. Zn, 0.1 p.p.m. Cu, 50 p.p.m. Mn.

Fifteen hundred ml of the nutrient solution were added just before seeding the oats. Additions of nutrient solution were made at regular intervals until the total added was 6 liters. Wolverine oats, a very susceptible variety, was seeded on February 2, 1942. Five ml of a molar solution of potassium nitrate were added at 10-day intervals.

On February 21, 19 days after seeding, the first characteristic lesion of grey speck developed on one of the plants growing in the culture receiving the purified chemicals with no manganese. Additional lesions developed very slowly for about 10 days, after which time they developed very rapidly. On March 14, all the plants had lesions with many of them in the advanced halo and dry spot stages. The tip of the leaf remained green for a time after the death of the tissue at the basal portion of the leaf. This is very characteristic of grey speck condition.

The plants which received the unpurified chemicals with no added manganese developed a few very primary lesions which were hard to detect and might easily escape observation.

The plants receiving the manganese salts did not develop lesions. Those receiving 50 p.p.m. of manganese became slightly chlorotic, indicating that the application was slightly toxic.

The treatments affected the growth of the oats. Very little difference in the growth existed between the treatments receiving manganese. The A-Z solution, containing elements known to exist in plants, did not give any additional benefit over the other treatments. The plants receiving no manganese made a much poorer growth than those receiving manganese. Those receiving the unpurified

chemicals with no added manganese made about twice as much growth as the ones receiving the purified chemicals. This indicates that the plants were able to get some manganese from the unpurified chemicals.

Chemical analyses of the leaves revealed that the manganese content of the oats grown on the purified culture was extremely low. The manganese content of the oats grown on the unpurified culture was three times as much as that of the plants grown on the purified culture. The leaves of the oats growing on the culture receiving 50 p.p.m. of manganese had 375 times as much manganese as those of the plants grown on the purified culture. The analyses also revealed that the iron content of the leaves decreased as the manganese content increased.

Table 1 gives the counts of the lesions on various dates and the yield. Fig. 1 shows specimens of lesions at different stages of development of the grey-speck condition.

DISCUSSION

The results obtained in this study show the importance of the use of specially purified materials in studying the nutrition of plants. The apparent failure of some experimenters to produce grey-speck in sand

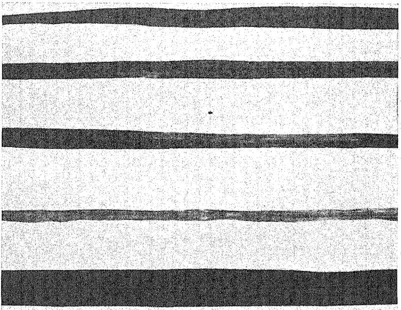


FIG. 1.—Development of various stages of grey speck. First leaf shows the initial greyish lesions; second, shows the transition from the greyish lesion to the halo stage; third, the advanced halo stage; fourth, the final dry spot-stage; and the fifth leaf is from a normal plant.

or water-culture studies is due to two causes. First, the chemicals used in the experiment contained sufficient manganese to prevent the development of grey speck. Second, culture solutions are usually slightly acid which condition has been shown to keep the manganese present in a very available form (9). When all known sources of manganese contamination were removed, the oats developed a very severe case of grey-speck in a sand culture having a pH of 6.0.

TABLE 1.—*The effect of the exclusion of manganese from the culture solution on the growth of oats and the development of grey speck.*

Treatment in addition to the "3-salt" nutrient solution	pH of culture solution	Percentage of plants showing grey speck							Chemical analysis of oat plants		Average yield of green oats, grams
		Feb.		March					Mn %	Fe %	
		21	26	2	7	14	18	21			
A-z solution (3)	5.8	0	0	0	0	0	0	0	0.0066	0.0090	189.9
No Mn, unpurified........	5.9	0	0	0	2	4	8	9	0.0009	0.0099	115.1
No Mn, purified	6.0	1	2	6	9	36	100	100	0.0003	0.0114	55.8
2 p.p.m. Mn....	5.8	0	0	0	0	0	0	0	0.0072	0.0088	194.3
50 p.p.m. Mn...	6.0	0	0	0	0	0	0	0	0.1120	0.0086	181.6

CONCLUSIONS

1. Oats developed grey speck when grown in a sand culture free of manganese.
2. The chemicals used in unpurified nutrient salt solution contained sufficient manganese to prevent grey speck from becoming serious.
3. Culture solutions containing 2 p.p.m. of manganese produced normal growth of oats.
4. The grey speck produced on these sand cultures is identical with that produced on manganese-deficient soil.

LITERATURE CITED

1. DAVIES, D. W., and JONES, E. T. Grey speck disease of oats. Welsh Jour. Agr., 7:349–358. 1931.
2. GERRETSEN, F. C. The effect of manganese deficiency on oats, in relation to soil bacteria. Trans. 3rd Int. Congress Soil Sci., I:189–191. 1935.
3. HAAS, A. R. C., and REED, H. S. Significance of traces of elements not ordinarily added to culture solutions for the growth of young orange trees. Bot. Gaz., 83:73–84. 1927.
4. HELLER, V. G., HAGEMAN, R. H., and HARTMAN, E. L. Sand culture studies of the use of saline and alkaline waters in greenhouses. Plant Phys., 15: 727–733. 1940.
5. LEEPER, G. W. Manganese deficiency of cereals, plot experiments and a new hypothesis. Proc. Royal Soc., Victoria, 47, II:255–261. 1935.
6. McHARGUE, J. S., and OFFUTT, E. B. Still for obtaining metal free distilled water. Ind. and Eng. Chem., 12:157. 1940.
7. PIPER, C. S. The availability of manganese in the soil. Jour. Agr. Sci., 21: 762–799. 1931.
8. RAY, T. W. A rapid means of obtaining manganese-free iron. Jour. Lab. and Clinical Med., 25:745–747. 1940.

9. SHERMAN, G. DONALD, and HARMER, PAUL M. Manganese deficiency of oats on alkaline organic soils. Jour. Amer. Soc. Agron., 33:1080–1092. 1941.
10. SJOLLEMA, B., and HUDVIG, J. Inquiry into the causes of the decrease in fertility of some soils in the Groningen and Drenthe Moor colonies. Verslog. Landouwk. Onderzoek. Rijkslandbouwproefstat. (Abstract in Exp. Sta. Rec., 21:115. 1909.)
11. STEENBJERG, F. The exchangeable manganese in Danish soils and its relation to plant growth. Trans. 3rd. Int. Congress Soil. Sci., I:198–201. 1935.
12. STEINBERG, R. A. Nutrient solution purification for removal of heavy metals in deficiency investigations with aspergillus niger. Jour. Agr. Res., 51:413. 1935.
13. STOUT, P. R., and ARNON, D. I. Experimental methods for the study of the role of copper, manganese and zinc in nutrition of higher plants. Amer. Jour. Bot., 26:144–149. 1939.

DUFF BRIQUETTE FERTILIZERS: THEIR PREPARATION, USE, AND EFFECT UPON THE GROWTH OF TREES AND OTHER PLANTS[1]

S. A. WILDE AND R. WITTENKAMP[2]

THE use of briquette fertilizers was introduced by the Chinese many centuries ago. In 1827, Sir Humphrey Davy (5)[3] gave the following account of this practice in his "Agricultural Chemistry": "The Chinese, who have more practical knowledge of the use and application of manures than any other people, mix their night soil with one-third of its weight of a fat marl, make it into cakes, and dry it by exposure to the sun. These cakes form a common article of commerce in the empire."

In recent years, a variety of tablets, pellets, and briquette fertilizers made of mineral salts alone or in combination with organic matter has been placed on the market or described (4, 6, 7).

The advantages of briquette fertilizers are considerable. As a rule, the salts in briquettes are slowly soluble and their gradual release offers a continued source of plant nutrients. In turn, danger of chemical injury to the roots and of an unbalanced state of the soil solution are largely eliminated. Competing grass vegetation is encouraged only to a small extent, especially when briquettes are applied at a considerable depth.

The application of briquettes in the field in some cases is more convenient than treatments with solutions or measured amounts of powdered fertilizers. When briquettes include suitable organic materials, additional benefits can be expected from increased activity of useful microorganisms, possible release of growth-promoting substances, and the introduction of minor nutrient elements which may be deficient in certain soils. Organic briquettes are particularly well suited for fertilization of trees, shrubs, and some other plants which are adapted to forest conditions and which require buffered fertilizers.

This paper outlines the main features of briquette fertilizer practice as initiated and carried on during the past few years in Wisconsin. Originally, the use of briquettes was intended to aid in the maintenance of landscape plantings made by the State Conservation Department. With the accumulation of experience, however, it became evident that fertilizers of this type may be successfully used in a much broader field, including floricultural, horticultural, and soil conservation work.

---

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis., in cooperation with the Wisconsin Conservation Department and the Department of Public Welfare. Publication approved by the Director of the Wisconsin Agricultural Experiment Station. Received for publication April 27, 1942.

[2]Associate Professor of Soils and District Forester, respectively. The writers are indebted to the Wisconsin Alumni Research Foundation for partial support of this work, and to Dr. H. L. Russell for his stimulating interest.

[3]Figures in parenthesis refer to "Literature Cited", p. 746.

COMPOSITION OF DUFF BRIQUETTES

The writers had observed on many occasions a remarkable beneficial influence upon the growth of trees and shrubs exerted by certain types of partially decomposed forest litter, or the so-called "duff" material. The friable duff layers from the productive mixed stands of hard maple, yellow birch, hemlock, and white spruce were shown by previous investigations to possess an especially high fertilizing value (9, 12).

The above type of organic remains was selected as the principal material for the preparation of briquettes. In order to obtain the necessary consistency, the humus was mixed with acid lacustrine clay (Superior soil series). The mixture was then treated with a solution of ammonium sulfate, potassium nitrate, and ammonium phosphate.

After a series of fertilizer trials, conducted in the field, greenhouse, and laboratory, the final formula was established as follows:

5 pecks of shredded hardwood-hemlock duff. Approximate reaction, pH 5.3; total N content, 1.5%; and base exchange capacity, 70 M.E. per 100 grams.
1 peck of pulverized Superior clay, having 35 to 45% of particles smaller than 0.005 mm in diameter; approximate base exchange capacity of 30 M.E. per 100 grams; and a reaction of pH 5.5.
2 pounds of ammonium sulfate (20% N).
2½ pounds of potassium nitrate (13% N; 44% K_2O).
1½ pounds of ammonium phosphate (11% N; 48% P_2O_5).

These amounts of materials are sufficient for the preparation of 100 2 × 2 × 4 inch briquettes, or 800 1 × 1 × 2 inch briquettes.

The composition outlined is the net result of many modifications tested during 3 years of experiments. The ratio of the nitrogen, phosphorus, and potassium, and the concentration of the fertilizer salts in the briquettes were given special attention. The properties of the briquette were adjusted in relation to several aspects, namely, fertilizing capacity of the briquettes, toxicity of salts in high concentrations, balance of nutrients, and losses of salts through leaching.

Among a number of treatments which have proved to be unnecessary or undesirable, the following should be mentioned: The addition of higher amounts of mineral colloids, the use of protecting protein and casein glues or collodion, admixture of peat having a high exchange capacity, and preliminary composting of the organic material used.

PREPARATION AND COST OF BRIQUETTES

In order to satisfy the needs of several state institutions, a small manufacturing unit was established in McNaughton State Forestry Camp, maintained by the Wisconsin Conservation Department in cooperation with the State Department of Public Welfare.

The power was provided by a small ½ H.P. electric motor, operating interchangeably a rotating screen for cleaning duff, a grinding machine, and a concrete mixer. The moulding forms were prepared

from $\frac{1}{16}$-inch sheet iron and consisted of 12 × 20 inch pans divided into small compartments (2 × 2 × 4 inches, or 1 × 1 × 2 inches).

In the preparation of briquettes, clay and duff are cleaned of stones and large wood fragments by passing the materials through a 1-inch screen. The duff is pulverized in a shredder. Measured amounts of clay, shredded duff, and commercial fertilizer salts are placed by means of calibrated scoops into a concrete mixer. Water is added in a quantity sufficient to make a semi-fluid suspension. The concrete mixer is run for 15 minutes and then the suspension is poured into the moulding trays. The trays are placed on shelves, and the briquettes allowed to dry for several days at a temperature not exceeding 90°F. When dry, the briquettes are removed from the forms and packed in special 20 × 16 × 10 inch rough-wood boxes which accommodate 200 large or 1,600 small briquettes.

The following estimate of costs is given per 1,000 of the large 2 × 2 × 4 inch briquettes:

Humus, sand, and clay at $10 per cubic yard	$ 5.00
Fertilizers at $100 per ton	3.00
Labor at $4.00 per day	10.00
Depreciation of equipment, insurance, supervision, etc.	7.00
Total	$25.00

The cost of one large briquette is, therefore, 2.5 cents. This figure is based on local experience and the cost may fluctuate as much as 100% in either direction, depending upon the conditions of production.

FERTILIZING VALUE OF BRIQUETTES

The content of total fertilizer salts is approximately equal to 0.1 gram per cc of the briquette. At this concentration of salts, an application of one small 1 × 1 × 2 inch briquette per square foot is theoretically equivalent to a broadcast application of 250 pounds per acre of concentrated fertilizers. Actually, the efficiency of briquette fertilizers is considerably higher than that of fertilizers applied broadcast, especially when the soils treated are of a coarse sandy texture or have a high fixing capacity.

In localized treatments of small plants, such as strawberries, one or two small briquettes per plant are usually sufficient to produce an abundant yield on poor sandy soil. In the fertilization of trees, two or three large briquettes take care, under average conditions, of about 10 square feet of the area penetrated by the roots. Thus, three large briquettes would provide adequate plant food for a 5- to 7-year-old blue spruce, whereas the restoration of old park trees on a sodded humus-deficient soil may require as many as 25 large briquettes. In raising tree seedlings and flowering plants in half-gallon glazed jars, one-eighth of a small briquette was found to be a suitable application.

No chemical injury to the plants from the application of briquettes was observed under field conditions, but in jars or other containers without drainage an application of more than 1 cubic inch of briquette material per gallon of soil was in some instances detrimental to plants.

Since the rate of fertilizer application depends greatly upon the composition of the soil, the nature of the plant, and the cost of the crop produced, it is difficult to give more specific recommendations. Table 1 presents information on the approximate fertilizing capacity of the large and small briquettes and may serve as a general guide in briquette fertilization.

TABLE 1.—*Fertilizing value of briquettes in terms of fertilizer salts and essential nutrients on acre basis.*

Area fertilized with one briquette, sq. ft.	Large briquettes, 2 × 2 × 4 inches		Small briquettes, 1 × 1 × 2 inches	
	Equivalent values of total fertilizer salts, lbs. per acre	Contents of soluble N, P_2O_5, and K_2O, lbs. per acre	Equivalent values of total fertilizer salts, lbs. per acre	Contents of soluble N, P_2O_5, and K_2O, lbs. per acre
1	2,000	296–238–364	250.0	37–30–45
2	1,000	148–119–182	125.0	18–15–22
4	500	74– 60– 91	62.5	9– 7–11
10	200	30– 24– 36	25.0	4– 3– 5

DUFF BRIQUETTES AS A SOURCE OF GROWTH-PROMOTING SUBSTANCES

One important property of duff briquettes appears to be their capacity to supply various growth-promoting substances (vitamins and hormones) common to productive types of upland humus and animal manures (1, 2, 3). The growth-promoting substances are released by specific microorganisms. The supply of these substances could hardly be maintained in the soil unless suitable organic residues are present to serve as a medium for their continued production and release.

The effect of the growth-promoting substances is particularly striking in the fertilization of trees and other forest vegetation grown on quartz sand or on prairie soils. Whatever the nature of these stimulants may be, they appear to be absolutely necessary for a normal growth of forest vegetation on nonforest substrata. This is the chief reason, the writers believe, why the effect of humus briquettes cannot be duplicated with mineral salts alone when applied to plants of forest origin in sand cultures or on prairie soils (8).

RATE OF REMOVAL OF FERTILIZER SALTS BY LEACHING

The study of the removal of fertilizers through leaching was conducted with three sets of 1 × 1 × 2 inch briquettes varying in their concentration of salts. Briquettes with salts in high concentration contained 2 grams of ammonium sulfate, 2.5 grams of potassium nitrate, and 1.5 grams of ammonium phosphate. One-half and one quarter of these amounts of fertilizers were used in the preparation of two other sets of briquettes.

Briquettes were placed on a moistened cotton pad in percolator cylinders 2 inches wide and 10 inches deep and covered with air-dry sandy soil. The soil was packed by tamping and brought to a saturated condition with 125 cc of water. After this, 600 cc of water were added to the columns, 10 cc at daily intervals. This amount of water corresponded roughly to a precipitation of 10 inches. The leachates were periodically evaporated, residues ignited, and total soluble salts determined.

The amounts of salts removed were directly proportional to the original concentration. The percolation of the first 150 cc removed about 25% of the salts from all the types of briquettes tested. After this the loss of nutrients decreased rapidly and the composition of the briquettes approached an equilibrium. The maximum amount of salts removed was 30% of the original content.

RATIO OF NUTRIENTS, CONCENTRATION OF SALTS, AND TOXICITY

In the original preparation of briquettes, the proportion of nitrogen, phosphoric acid, and potash was maintained at the ratio of 2:3:5, i.e., a ratio approaching the composition of the virgin forest soils (10, 11) as regards available nutrients. In the course of pot culture studies with a variety of plants, it was found desirable to double the proportion of soluble nitrogen. No improvement was obtained by altering the relative amounts of phosphate and potash, and the optimum ratios were found to be in the neighborhood of 4:3:5. In spite of the considerable instability of nitrates, it was found advantageous to supply at least a part of the soluble nitrogen in this form.

The freedom of briquettes from the toxic effects of highly concentrated salts was judged by the ability of roots to penetrate the pellet, by the appearance of the root systems in proximity of the briquette, and by the general development of the plant. These aspects were investigated with a variety of trees and herbaceous plants in the field and in the greenhouse. Fig. 1 illustrates some of the results obtained. On the basis of these investigations, the maximum safe concentration of fertilizer salts was found to be 0.1 gram. per cubic centimeter of the briquette material.

EFFECT OF BRIQUETTE FERTILIZERS UPON PLANT GROWTH

The effect of briquette fertilizers on trees, ornamental shrubs, berries, garden crops, and flowering plants was investigated. In addition to sample plats and greenhouse trials, carried on by the writers themselves, several thousand briquettes were distributed among various state employees and private individuals engaged in growing plants. A brief summary of the results obtained and a few representative data are reported below.

The briquettes have proved to be about the best form of fertilizer for the treatment of *starving* trees. Almost invariably, the application of briquettes on soils deficient in certain nutrients or depleted in organic matter has improved the color and general appearance of both hardwoods and conifers. According to reports of several land-

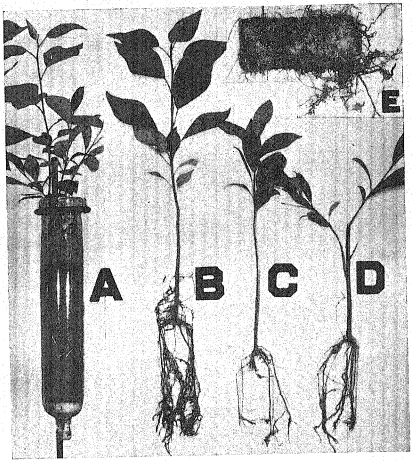


FIG. 1.—Effect of concentration of salts in briquette fertilizers upon the development of roots. A and B, 4-week-old cottonwood cuttings grown in percolators with briquettes containing approximately 0.1 gram of commercial fertilizer per cc. Note vigorous development of the root system. C and D, similar cuttings grown with briquettes containing 0.5 gram of commercial fertilizer per cc. Root development is inhibited by the high concentration of salts. E, a suitable concentration of salts is indicated by the penetration and abundant growth of roots into and around the briquette.

scape architects, particularly satisfactory results were obtained with Colorado blue spruce. Striking beneficial results were observed with white pine, paper birch, cottonwood, rhododendron, black locust, elm, white ash, and mountain ash. In several instances, the application of briquettes has arrested the deterioration of older or injured trees. This regenerating effect of the fertilizer was especially marked on poorly drained soils, soils of calcareous origin, and prairie soils.

While the application of fertilizer produced in most instances an improvement in the vigor of planted trees, the increase in the rate of

tree growth, particularly that of the light-demanding pioneer species, was subject to wide variation. As a general rule, the increase in the height growth of older trees was very small during the first growing season following the application of the fertilizer. In a number of cases, only a few per cent increase in the height growth of pine and other light-demanding species was recorded during the first two growing seasons. In an extensive study of plantations in the American Legion Forest, Wisconsin, an application of four large briquettes to each 5-year old red pine tree resulted in an average annual height increase of 5½ inches, or about 14% over unfertilized trees. Somewhat higher increases in the rate of growth were recorded along the shore of a lake where the trees apparently were benefited by the capillary action of the ground water.

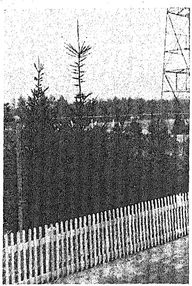


FIG. 2.—An abnormal increase in height growth of white spruce (two trees in foreground) produced by excessive application of briquettes in combination with artificial watering. A condition which may lead to damage of trees by ice, snow, drought, or wind.

A quick and vigorous response to fertilizer was observed in the application of briquettes to trees grown with artificial irrigation. This was true with seedlings and transplants of all species, even when the briquettes were applied in the manner least acceptable for nursery practice, i.e., as a surface application similar to top dressing. The rate of application ordinarily varied from one to two small briquettes per square foot.

The treatment of large nursery blocks with briquette fertilizer is prohibitive because of its high cost. Yet, briquettes present an extremely valuable auxilliary means for the improvement of small patches of retarded or accidentally injured nursery stock.

In an experimental treatment of windbreak trees in the Griffith State Forest Nursery, Wisconsin, heavy applications of briquettes produced, in some instances, an enormous increase in the height growth of white spruce (Fig. 2). Such heavy applications on artificially watered soils are undoubtedly dangerous from the standpoint of frost injury and should be avoided.

In a few instances an appreciable increase in the production of apples and other fruits was reported. However, no systematic survey was made to verify these casual observations.

In trials with berries, the most conspicuous results were achieved with strawberries. An application of two small briquettes per plant

to old plants or young rooted cuttings increased greatly the number and size of the berries and improved the general appearance of the plants (Fig. 3). Similar, highly satisfactory results were obtained with a variety of garden crops and flowers raised in beds.

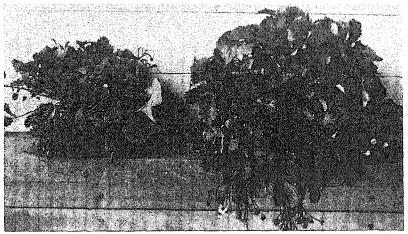


FIG. 3.—Effect of briquette fertilizer upon the growth of strawberries. *Left*, unfertilized strawberry plant on a podzolized sandy loam soil deficient in humus and nutrients. *Right*, strawberry plant on the same soil fertilized with two small briquettes applied on the surface. Marked increase in number amd size of berries resulted from fertilization.

The fertilization of potted plants proved very successful when the fertilizer was applied in a suitable quantity, not exceeding 1 cubic inch of briquette per gallon of soil. With periodic small applications of briquettes, geraniums attained about 40 inches in height in a livin; room with rather inadequate side light (Fig. 4). Many completely stagnant potted flowers, ferns, and creeping plants were brought to a prolific growth. Briquettes applied to flowering plants in jars did not lose their potency for a period of 2 years, as indicated by vigorous blooming.

METHODS OF BRIQUETTE PLACEMENT

Briquettes are applied in three ways, *viz.*, in planting holes at the time of planting, as side applications in slits made by means of a bar or other suitable tool, and as surface applications similar to top dressings.

At the time of planting, one or more briquettes are placed at the bottom of the planting hole and are covered with a thin layer of soil to prevent immediate contact of the roots with the fertilizer. This method assures the rapid accessibility of fertilizer to the root systems and hence a maximum utilization of nutrients. The cost of labor involved in the application of briquette fertilizer by this method is negligible.

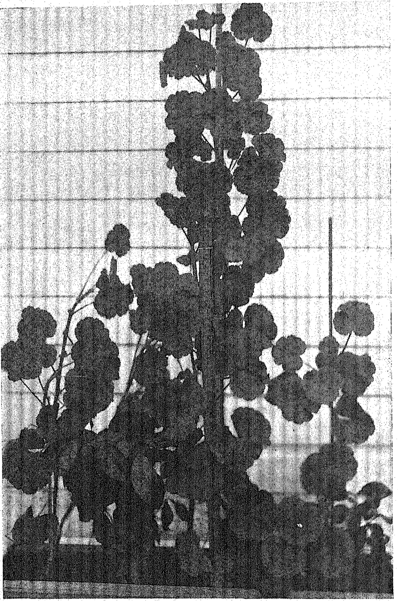


FIG. 4.—Effect of briquette fertilizer upon the growth of a geranium raised under room conditions. From early March until May the central plant grew from the original height of a few inches to 5 feet.

The deep application of briquettes to growing plants on sandy, stone-free soils is made by means of a tree planting bar with a nar-

rowed blade, 2½ inches wide and 10 inches long. On heavy and stony soils it is more convenient to use a modified post hole digger, a mattock, or an auger. This mode of application does not encourage the development of shallow superficial root systems which is often undesirable. The cost of the deep application of briquettes is considerable, especially on heavy soils.

The application of briquettes on the surface is a cheap method well adapted to the fertilization of rapidly growing plants. However, it has certain disadvantages. When the briquettes are applied on the surface, their salts tend to diffuse over a considerable area and thus promote the growth of competing vegetation. This method may partially arrest the desirable development of deep root systems. Some losses of fertilizing material from water and wind erosion are to be expected. On light soils these losses may be eliminated by pressing the briquettes into the ground with the foot.

In treatment of growing plants, it is important to place the briquettes as closely as possible to the feeding roots. This is simple in fertilizing garden crops of flowers, but requires a certain skill in fertilizing older trees. As a rule, the spread of tree roots coincides rather closely with that of the crown. Digging trenches around a few trees may help to establish the root-crown relationship for a certain species and type of soil.

SUMMARY

This paper outlines the principles of the preparation and use of duff briquette fertilizers as initiated and carried on during the past several years in Wisconsin. Briquettes are made of a mixture of hardwood-hemlock duff, lacustrine clay, and fertilizer salts. The finished briquettes contain 0.1 gram of total fertilizer salts per cc and have an N-P-K ratio approaching 4:3:5. This composition was chosen after investigation and consideration of the fertilizing capacity of briquettes, toxicity of salts in high concentrations, balance of nutrients, and losses of salts through leaching. The cost is estimated at 2.5 cents per 16 cubic-inch briquette.

Three methods of briquette placement were used, *viz.*, in planting holes, in slits, and as top dressing. The latter method proved successful only with rapidly growing garden crops.

The briquettes were used chiefly in the fertilization of plants in public parks, camping grounds, nurseries, gardens, landscape plantings, and roadside shelterbelts. Very satisfactory results were obtained with ornamental trees and shrubs, nursery beds, berries, truck crops, and flowering plants. Many dwarfed and ailing plants were brought to a prolific growth. The plants which are naturally adapted to forest soils and require buffered organic fertilizers responded especially well to the application of briquettes. The favorable effect of the briquette fertilizer was greatly increased under conditions of artificial watering. Indirect evidence indicated that the beneficial effect of duff briquettes is partly due to the release of growth-promoting substances.

The results obtained in the fertilization of forest plantations established on cut-over areas were subject to wide variations. An appreci-

able increase in the rate of tree growth was observed only on soils which were radically deficient in certain nutrient elements, depleted in organic matter, or had not previously supported forest vegetation. Plantations of light-demanding pioneer species, particularly pines, on fairly productive sandy soils showed but a small average increase in height growth due to fertilization with briquettes.

With some exceptions, the results obtained from the application of duff briquettes were greatly superior to those obtained with an application of ordinary mineral fertilizers.

LITERATURE CITED

1. BREAZEALE, J. F. Vitamin-like substances in plant nutrition. Ariz. Agr. Exp. Sta. Tech. Bul. 16. 1927.
2. BONNER, J., and GREENE, J. Vitamin B in the growth of green plants. Bot. Gaz., 100:226–237. 1938.
3. EULER, K. V., BURSTROM, D., and GUNTHER, G. Studien on Phytohormonen. Svensk. Kem. Tidskr., 46:250. 1934.
4. HANCE, F. E. Preparation of fertilizer briquettes and their utilization in general agricultural practice. Trans. 3rd Int. Cong. Soil Sci., 1:258–260, 1935.
5. HOPKINS, Cyril G. Soil Fertility and Permanent Agriculture. Boston. 1910.
6. LIEHR, W., and DYCKERHOFF, E. Method of preparing a peat-containing fertilizer. U. S. Patent Office, Patent No. 2,019,824. 1935.
7. MELVIN, J. K., and MCCOMB, A. L. Response of American elm to loose and briquette fertilization in the greenhouse. Jour. For. 40:49–51. 1942.
8. WHITE, D. P. Prairie soil as a medium for tree growth. Ecology, 22:399–407. 1941.
9. WILDE, S. A. The use of liquid humate fertilizers in forest nurseries. Jour. For., 35:388–392. 1937.
10. ————. Soil-fertility standards for growing northern conifers in forest nurseries. Jour. Agr. Res., 57:945–952. 1938.
11. ————. A balanced diet for nursery stock. Better Crops with Plant Food. 5–6:14. 1941.
12. ————, BURAN, S. F., and GALLOWAY, H. M. Nutrient content and base exchange properties of organic layers of forest soils in the Lake States Region. Soil Sci., 44:231–239. 1937.

THE EFFECT OF NITROGEN FERTILIZATION OF PERMANENT PASTURES ON SEASONAL DISTRIBUTION OF YIELDS AND ON NITROGEN RECOVERY IN THE HERBAGE[1]

R. R. ROBINSON AND W. H. PIERRE[2]

AMONG the most important criteria determining the economy of applying nitrogen fertilizers to permanent pastures are the actual increases in herbage yields, the seasonal distribution of the yields, and the nitrogen recovery in the herbage. In a previous publication, the writers (12)[3] reported the effect of nitrogen and other fertilizers on the yield and the botanical composition of pastures. It is the object of this paper to present some of the data secured in these same experiments relative to (a) the effect of nitrogen fertilizers applied in single and split application on the seasonal distribution of yields, and (b) the percentage of the nitrogen applied in the fertilizer that is recovered in the herbage.

The studies were conducted on old established pastures on three soils, a Westmoreland silt loam, a Huntington silt loam, and a Dekalb silt loam. The experimental areas were divided into a number of 0.002 acre plots, topdressed with various combinations of fertilizer and lime in quadruplicate, and clipped, usually four to six times a year, with a lawn mower. During 1930 to 1932 the mower was set to cut at a height of 1¼ inches, whereas during 1933 to 1936 it was set to cut at a height of 2 inches. In 1937 the plots were cut to a height of 1½ inches.

The clippings were dried to a moisture content of about 1½% and the yields of dry herbage and the percentage nitrogen content are both reported on this moisture basis.

EFFECT OF SINGLE AND SPLIT APPLICATIONS OF NITROGEN ON TOTAL AND SEASONAL DISTRIBUTION OF YIELDS

The area selected for studying the effect of nitrogen fertilization on seasonal distribution of yields was on one of the better upland pasture soils, a Westmoreland silt loam having a smooth topography and about 8 inches of top soil. A more complete description of this soil is given in an earlier publication (12). The fertilizer treatments and yields of herbage are shown in Table 1.

The effect of nitrogen fertilization on the yield of herbage is so closely related to the botanical composition of the pasture that the increase in yield cannot be discussed independently of the botanical

[1]Cooperative investigations of the West Virginia Agricultural Experiment Station, Morgantown, W. Va., and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Scientific Paper No. 285 of the West Virginia Agricultural Experiment Station. Received for publication April 28, 1942.

[2]Associate Agronomist, U. S. Dept. of Agriculture, and former head of the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, respectively. The preparation of this paper was completed while the writers were with the U. S. Regional Pasture Research Laboratory, State College, Pa., and the Iowa Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 763.

TABLE 1.—*Summary of the yield response to nitrogen fertilization on the Westmoreland silt loam.*

Plot No.*	Treatment†	Yield of herbage, lbs. per acre								Average, 1932–37
		1931‡	1932	1933	1934	1935	1936	1937	Average	
5, 10, 14, 18	None	1,940	1,162	1,103	622	850	806	1,745	1,175	1,048
1	P	2,186	1,412	1,635	694	955	889	1,952	1,389	1,256
2	P-K	2,199	1,277	1,658	655	890	775	1,735	1,313	1,165
3	N-P (Mar. 100, June 100)	2,238	1,614	2,358	1,054	1,360	1,129	2,523	1,754	1,673
4	N-P-K (Mar. 200)	2,618	1,684	2,342	1,095	1,388	1,137	2,523	1,827	1,695
6, 13	N-P-K (Mar. 100, June 100)	2,486	1,606	2,424	1,019	1,435	1,158	2,541	1,810	1,697
7	N-P-K (Mar. 100, July 100)	2,542	1,586	2,359	1,004	1,214	1,043	2,418	1,738	1,604
8	N-P-K (Mar. 100, June 50, Aug. 50)	2,424	1,554	2,603	1,074	1,475	1,218	2,627	1,854	1,758
9	N-P-K (Mar. 50, June 50, July 50, Aug. 50)	2,870	1,561	2,590	1,191	1,367	1,218	2,612	1,916	1,756
11	N-P-K (Mar. 50, June 100, Aug. 50)	2,530	1,525	2,330	955	1,396	1,154	2,580	1,781	1,657
12	½N-P-K (Mar. 100)	2,600	1,513	2,008	785	1,243	1,037	2,336	1,646	1,487
15	½N-P-K (Mar. 50, June 50)	2,567	1,513	2,228	858	1,221	991	2,168	1,649	1,496
16	½N-P-K (June 100)	2,305	1,372	2,012	873	1,256	1,081	2,197	1,585	1,465
17	½N-P-K (June 50, Aug. 50)	2,465	1,401	2,279	818	1,256	1,053	2,264	1,648	1,512
	Av. of P and P-K	2,192	1,344	1,646	674	922	832	1,843	1,352	1,210
	Av. of all ½N-P-K plots	2,484	1,450	2,132	833	1,244	1,040	2,241	1,632	1,490
	Av. of all N-P-K plots	2,565	1,589	2,439	1,051	1,387	1,155	2,549	1,819	1,695

*Every plot number is in quadruplicate.

†P = 500 lbs. per acre of 20% superphosphate in first and third years; K = 100 lbs. per acre of muriate of potash in first and third years; N = 200 lbs. of nitrate of soda each year; ½N = 100 lbs. of nitrate of soda per year. The time of applying the nitrogen fertilizer is shown in parentheses. (Mar. 100), for example, means 100 lbs. per acre of nitrate of soda in March.

‡Exclusive of the July cutting, which was lost. This explains the low yields obtained where a large part of the nitrogen was applied in June.

composition. Since, however, the data on the botanical composition of the plots have been reported elsewhere (12), only a summary will be given here. The area averaged about 50% Kentucky bluegrass at the time the experiment was started in 1931. The estimated percentage of Kentucky bluegrass decreased after 1933 and in the fall of 1936 averaged only 12, 27, and 37, respectively, on the PK, ½N-P-K, and N-P-K- plots, the dominant species being poverty grass (*Danthonia spicata*). This marked decrease in the percentage of Kentucky bluegrass, particularly on the PK plots, is attributed largely to the combined effect of the continuous clipping, a deficiency of available nitrogen, and the occurrence of two droughty seasons (1934 and 1936). In 1931 and 1933 white clover averaged 12% of a stand, except during the early spring; other years the percentage was much less. Nitrogen fertilizer, in the amounts used, did not decrease the percentage of clover; in fact, in 1933, the percentage stand averaged slightly higher on the nitrogen-treated plots.

The data in Table 1 indicate that over the 7-year period the average increases in yield of herbage per unit of nitrogen fertilizer were independent of the time the nitrogen fertilizer was applied. The four plots that received 200 pounds per acre of nitrate of soda in the spring averaged 1,827 pounds per acre of forage as compared with 1,818 pounds for the 24 plots that received the same amount of nitrogen at various times during the season. Similarly, the four plots that received 100 pounds per acre of nitrate of soda in the spring averaged 1,646 pounds per acre as compared with 1,627 pounds for the 12 plots that received the same amount of nitrogen at various times during the season. These comparisons, however, are not quite fair to the plots that received summer applications of nitrogen because in 1931 cattle broke into the area two or three weeks after the June application of nitrogen and, although the area was only lightly grazed, the July cutting had to be discarded. Since excellent growth had been made during that period, most of the effect of the June application of nitrogen was lost.

If the data for 1931 are omitted, the average yields of the plots that received 200 pounds of nitrate of soda in the spring were exactly the same as the average for the corresponding plots that received split applications of nitrogen. Where 100 pounds of nitrate of soda were applied, the average yields were 1,487 pounds for nitrogen applied in the spring and 1,491 for nitrogen applied at various times during the season. These results may seem rather surprising since ordinarily there is much better growth of pastures during the spring than during other seasons of the year and, consequently, it might be expected that the total response to nitrogen would be greater from applications at that time. The explanation for the results obtained apparently lies largely in the fact, more fully shown later, that summer applications of nitrogen in years of unfavorable summer growing conditions are utilized later when growing conditions again become favorable.

Of probably greater importance than total yields of pasture herbage is the seasonal distribution of the yield (Fig. 1). Since all treatments cannot be included, the two most widely divergent are shown. They

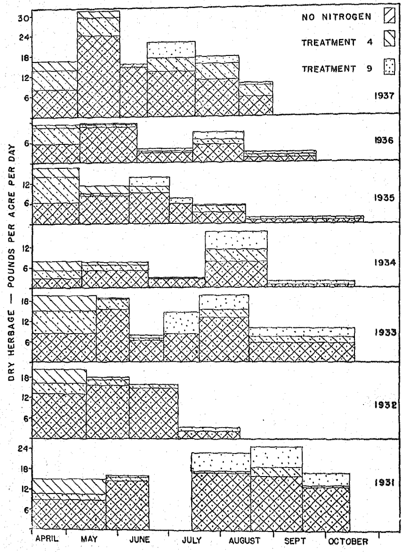


FIG. 1.—Seasonal production of herbage from single as compared with split applications of nitrogen on the Westmoreland silt loam. Treatment No. 4 received 200 pounds per acre of nitrate of soda every spring. Treatment No. 9 received the same amount of nitrogen but in four applications of 50 pounds each. The dates of the summer applications of nitrogen were as follows: 1931: June 20, July 15, and Aug. 18; 1932: July 8 and Aug. 12 (since only two applications were made, the rate was doubled on Aug. 12); 1933: June 28, July 19, and Aug. 17; 1934: June 19, July 23, and Aug. 28; 1935: June 7, July 15, and Aug. 15; 1936: June 12, July 15, and Aug. 14; 1937: June 18, July 16, and Aug. 11. In calculating the average rate of growth for the first period in the spring, it was assumed that growth started on April 10. No yields were obtained between June 20 and July 15, 1931, because cattle broke into the area.

are (a) 200 pounds of nitrate of soda applied in the early spring, and (b) the same total amount of fertilizer applied in four applications of 50 pounds each distributed throughout the season.

The daily precipitation and the daily maximum and minimum temperatures for 1931–36 are given in Fig. 1 of a previous publication (12).

The striking feature of the 1931 season was the extremely high yields during mid- and late-summer. The rather slow start in the early spring despite the rather high percentage of Kentucky bluegrass may have been due partly to low reserves resulting from close grazing the previous fall. Moreover, several periods of relatively cold weather were experienced during May and the latter part of April in 1931. Undoubtedly this was a factor in retarding early spring growth. Two hundred pounds per acre of nitrate of soda applied in the spring of 1931 produced a marked increase in yield of dry forage in the first cutting (277 pounds per acre), but in the second and subsequent cuttings the increases were small. On the other hand, the same amount of nitrogen applied in smaller applications at intervals during the summer resulted in marked increases throughout the season.

The summer of 1932 was very dry and, consequently, very little growth was made after the first of July. Thus, although spring applications of nitrogen gave marked increases in yield, the summer applications were ineffective during that season.

The 1933 season was very favorable for pasture growth and, as in 1931, nitrogen fertilizer resulted in marked increases in yield. The relatively large increase in the first cutting from the light application of nitrogen in the early spring was due partly to the carry-over from 1932. As shown in Fig. 1, part of the nitrogen in 1932 was applied after the last cutting.

The relatively poor growth on the nitrogen-treated plots in the second and third cuttings is not surprising since no nitrogen was applied between early spring and June 29. An application of 50 pounds of nitrate of soda on June 29 nearly doubled the yield during the next 21 days and similar applications on July 19 and August 17 materially increased the yields during the remainder of the season. It is evident, therefore, that in favorable growing seasons, such as 1931 and 1933, a more uniform seasonal growth can be obtained by applying part of the nitrogen during mid-summer than by applying it all in the early spring.

During the spring of 1934 nitrogen fertilization gave an excellent percentage increase in yield, but since rainfall was abnormally low and growth very poor on the no-nitrogen plots, the actual increase was small. During late July and August, with a high total although poorly distributed rainfall, the growth was better and a marked response to nitrogen fertilization was obtained. This was especially true where summer applications of nitrogen had been made.

A marked response to nitrogen fertilizer was evident in the spring of 1935. Probably part of this response can be attributed to the higher percentage of Kentucky bluegrass on the nitrogen-treated plots. The fact that the yields were nearly as high where 50 pounds of nitrate of soda were applied as where 200 were applied probably was due part-

ly to the carry-over effect from nitrogen applied during the previous summer. Pasture growth was poor during the latter part of the season, and although summer applications of nitrogen gave a high percentage increase in yield, the actual increase was small.

The entire 1936 season was abnormally dry and even in the first cutting in the spring the effect of the dry weather on the yields of herbage was apparent. Nevertheless, the nitrogen treatment doubled the yield of herbage in the first cutting. Undoubtedly part of this increase was due, as in 1935, to the higher percentage of Kentucky bluegrass on the nitrogen-treated plots. It will be noted that again the 50-pound application of nitrate of soda in the spring was almost as effective as the 200-pound application. This undoubtedly was due partly to the carry-over effect from nitrogen applied in the late summer of 1935 on the plots receiving the split applications and partly to the dry weather in 1936, which prevented maximum utilization of the larger spring application of nitrogen.

In 1937, with favorable growing conditions, high yields were obtained even where no nitrogen was applied. On the other hand, in view of the dry weather in 1936 and the latter half of 1935, soil ammonification and nitrification probably proceeded at rapid rates in 1937 when moisture was more favorable. Moreover, as was stated earlier, the plots were clipped somewhat closer in 1937 than during the preceding years. This would tend to favor the utilization of the organic reserves stored during 1936, when the soil was too dry to permit rapid growth.

Despite the high yields on the no-nitrogen plots in 1937, a very good response to nitrogen fertilization was shown. Where nitrogen was applied at frequent intervals during the season high yields were maintained until the middle of August. Applying all of the nitrogen in the early spring gave less uniform distribution of yield than the split applications, yet marked increases in yield were obtained even during the latter part of the season. It is believed, however, that the increase in yield in July and August from the early spring application of nitrogen was due partly to the better sod that had been built up over a period of several years.

The average seasonal production of herbage over the 7-year period is shown in Fig. 2. Where 200 pounds of nitrate of soda were applied in the spring (treatment No. 4), a marked peak in the average growth curve resulted. The total production in April and May amounted to about 42% of the total for the season, as compared with 35% for the no-nitrogen plots. Applying the same total amount of nitrogen in four equal applications (treatment No. 9) resulted in a more uniform average growth curve with 33% of the season's growth occurring in April and May.

Although the detailed seasonal response is shown for only two of the nitrogen treatments, the results serve to illustrate the response obtained from nitrogen fertilization in this experiment. When nitrogen was applied during favorable weather conditions the response occurred immediately; when applied during adverse weather, most of the response occurred when growing conditions again became favorable.

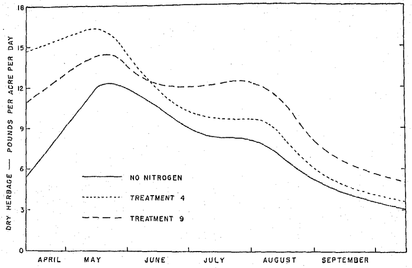


FIG. 2.—Seasonal production of herbage on the Westmoreland silt loam as affected by time of application of nitrogen fertilizer. Average of 7 years. See Table 1 for legend to treatments.

RECOVERY OF FERTILIZER NITROGEN

Studies were made during 1930 to 1936 of the percentage of the fertilizer nitrogen recovered in the clipped herbage from pastures on a Huntington and on a Dekalb soil. The fertilizer nitrogen recovered in the herbage was assumed to be equal to the difference between the amount of nitrogen harvested from the nitrogen-treated plots and that from the corresponding no-nitrogen plots. The area of Huntington soil is representative of the best bottomland pastures in the state and supported an excellent stand of Kentucky bluegrass when the experiment was started in 1930. The area of Dekalb soil is representative of a considerable portion of the less fertile upland pastures, being strongly acid (pH 5.0) and very low in available phosphorus. In 1930, when the experiment was started, the latter area was estimated to contain 58% native grasses, largely poverty grass (*Danthonia spicata*), with smaller amounts of broomsedge (*Andropogon virginicus*), 19% weeds, 7% bare space, 2% white and red clovers, and 14% Kentucky bluegrass and red top. A fuller description of these soils and of the character of the vegetation is given in another publication (12).

HUNTINGTON SILT LOAM

Since there was an excellent sod of Kentucky bluegrass on the Huntington soil when the experiment was started in 1930, lime and fertilizers had relatively little effect on the botanical composition except in years when clover was present. The variations in the clover populations, however, resulted in wide differences in percentage nitrogen recovery. There was practically no white clover on the area

until the fall of 1932. During 1933 the white clover spread rapidly. On the P-K-L plots, as shown in Table 2, the estimated stand of clover averaged about 30% during midsummer and fall. It is believed, however, that the clover made up much more than 30% of the total yield of herbage. Nitrate of soda applied in the early spring of 1933 at the rate of 100 pounds per acre (½N-P-K-L treatment) resulted in much less white clover during the spring and early summer, but by the latter part of the season the percentage of clover was about the same as on the P-K-L plots. The N-P-K-L plots, which received 100 pounds per acre of nitrate of soda in the spring plus 100 pounds in mid-summer, contained much less clover than the no-nitrogen and the ½N-P-K-L plots. Since the ½N and the N plots received the same nitrogen treatments in 1933 prior to July 6, the lower percentage of clover in the spring on the N plots (6% as compared with 12% for the ½N plots) probably was due to the carry-over effect from the previous year. The 2N treatment produced very striking reductions in the percentage of white clover. On June 13 these plots averaged only 2% white clover as compared with 25% for the corresponding no-nitrogen plots. By the end of the season, however, the percentage of clover had increased considerably on the high-nitrogen plots.

TABLE 2.—*The estimated percentage of white clover on various plots on the Huntington silt loam in 1933.*

Plot treatment*	Estimated percentage stand of white clover		
	June 13	July 29	Sept. 12
None	11†	8	15
P-K-L	25	32	31
½N-P-K-L	12	24	32
N-P-K-L‡	6	13	20
2N-P-K-L‡	2	7	13

*All treatments in quadruplicate. P = 500 lbs. per acre of 20% superphosphate in first and in third years. K = 100 lbs. per acre of muriate of potash in first and in third years. L = Ground limestone at the beginning of the experiment in accordance with the lime requirement. ½N = 100 lbs. per acre of nitrate of soda every spring. N = 200 lbs. per acre of nitrate of soda per year, applied half in early spring and half in early summer. 2N = 400 lbs. per acre of nitrate of soda per year, applied half in early spring and half in early summer.

†Partly hop clover.

‡The summer application of nitrogen to these plots was made on July 6.

Clover was also abundant in the spring of 1934 but largely disappeared during that summer and was present only in small amounts in 1935.

The effect of nitrogen fertilizers on the yield of herbage, the percentage nitrogen content of the herbage, the yield of nitrogen, and the percentage nitrogen recovery are summarized in Table 3. This table can be better understood, however, by first considering in more detail the effect of nitrogen fertilization during two seasons, 1931 and 1933. Both of these years were better than average years for pasture growth, but white clover was absent in 1931 and abundant in 1933.

During 1931, as shown in Fig. 3, nitrogen fertilizers, especially when used in large amounts, produced marked increases in both yield of herbage and percentage nitrogen content of the herbage. Conse-

quently, there were large increases in the yield of nitrogen. As would be expected, the effect of the nitrogen fertilizer was most pronounced in the first cutting after the application, although the heavy rate of application gave a very good response in the second cutting. The P-K-L treatment had little effect on either the yield or the nitrogen content of the herbage. The response to fertilization during 1931 is also representative, in general, of the response during the other years when white clover was absent or present in only small amounts (1930, 1932, and 1935), except that since the growing season was more favorable, the yields were higher in 1931.

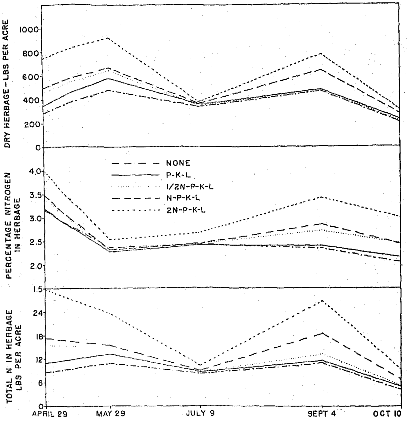


FIG. 3.—The seasonal response to fertilization on the Huntington silt loam in 1931 with clover absent. The N-P-K-L and the 2N-P-K-L plots received the summer application of nitrogen on July 9.

The response to nitrogen fertilization when clover was abundant is shown in Fig. 4. It will be noted first that in contrast to 1931, when clover was absent, the P-K-L treatment gave marked increases both in yield and in the percentage nitrogen content of the herbage. This is not surprising since, as was shown in Table 2, the P-K-L treatment

resulted in a marked increase in the percentage stand of white clover. The ½N treatment produced a very slight increase in yield of herbage early in the season, but decreased the yield during June; thereafter there was no appreciable effect. The percentage nitrogen content of the herbage from the ½N-P-K-L plots, however, was lower during May, June, and July than that from the P-K-L plots. This decrease in the nitrogen content of the herbage from nitrogen fertilization is attributed to a decrease in the percentage of clover (Table 2).

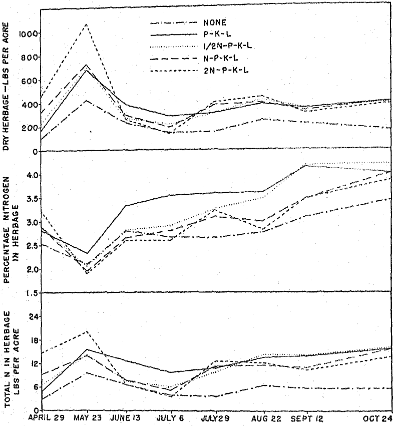


FIG. 4.—The seasonal response to fertilization on the Huntington silt loam in 1933 with white clover abundant. The N-P-K-L and the 2N-P-K-L plots received the summer application of nitrogen on July 6.

The N nitrogen treatment produced a larger yield of herbage in the first cutting than the ½N treatment, probably due partly to the carry-over effect from the 1932 season. Because of the dry weather no cuttings were made in 1932 after the summer application of nitrogen fertilizer. During the latter part of the summer, a marked reduction in the nitrogen content of the herbage from the N as com-

pared with the ½N treatment was obtained. This resulted from the reduction in the percentage of clover following the summer application of nitrogen.

The effect of the heavy nitrogen application (2N treatment) was somewhat similar to, but more striking than, that of the lighter applications of nitrogen. This is also shown in Fig. 4. In the first two cuttings after the spring application of nitrogen the luxuriant growth of bluegrass on the high-nitrogen plots yielded far more dry matter than the mixture of bluegrass and clover on the corresponding no-nitrogen plots. In the third and fourth cuttings, with but little clover present on the high-nitrogen plots and not much stimulation from the nitrogen, the yield was somewhat less than from the mixture of bluegrass and clover on the no-nitrogen plots. The second application of nitrogen was made immediately after the fourth cutting and for the next two cuttings the nitrogen plots yielded slightly more than the no-nitrogen plots but thereafter yielded slightly less. The percentage nitrogen content of the herbage from the 2N-P-K-L plots, however, was higher than from the P-K-L plots in only the first of

TABLE 3.—*Summary of the response to nitrogen fertilization on the Huntington silt loam.**

Plot treatment†	1930	1931	1932	1933‡	1935	Average	
						All years	Years of 1930, 1931, 1932, 1935
				Yield of Herbage, Lbs. per Acre			
None	643	1781	729	1674	1150	1195	1076
P-K-L	686	1998	951	2949	1405	1598	1260
½N-P-K-L	829	2151	1112	2865	1600	1711	1423
N-P-K-L	866	2458	1237	3030	1852	1889	1603
2N-P-K-L	1001	3144	1488	3420	2065	2224	1925
				Nitrogen Content of Herbage, %			
None	2.04	2.42	2.00	2.61	2.21	2.26	2.17
P-K-L	2.14	2.43	2.10	3.28	2.22	2.43	2.22
½N-P-K-L	2.34	2.63	2.10	3.09	2.13	2.46	2.30
N-P-K-L	2.47	2.68	2.13	2.84	2.37	2.50	2.41
2N-P-K-L	2.75	3.11	2.33	2.73	2.43	2.67	2.66
				Yield of Nitrogen, Lbs. per Acre			
None	13.1	43.1	14.6	43.7	25.4	28.0	24.0
P-K-L	14.7	48.6	20.0	96.6	31.2	42.2	28.6
½N-P-K-L	19.4	56.6	23.3	88.4	34.1	44.4	33.4
N-P-K-L	21.4	65.9	26.4	86.0	43.9	48.7	39.4
2N-P-K-L	27.5	97.8	34.6	93.5	50.1	60.7	52.5
				Nitrogen Recovery, %			
½N-P-L-K	29	50	21	−51	18	—	30
N-P-K-L	21	54	20	−33	40	—	34
2N-P-K-L	20	77	23	−5	30	—	37

*The nitrogen content of the herbage was not determined for the 1934 season.
†All treatments in quadruplicate. See Table 2 for description of treatments.
‡White clover abundant. None or only small amounts present during other years.

the eight cuttings. The yield of nitrogen from the 2N-P-K-L plots was higher than from the P-K-L plots in the first two cuttings after the spring application of nitrogen and in the first cutting after the summer application, but was lower in the other five cuttings. The total yields per acre of nitrogen, shown in Table 3, were 96.6 pounds for the P-K-L plots and 93.5 pounds for the 2N-P-K-L plots.

The percentage nitrogen recovery values, summarized in Table 3, show that when clover was absent or present in only small amounts the recovery ranged from 50 to 77% for the favorable year of 1931, as compared with 18 to 40% for the less favorable seasons (1930, 1932, and 1935). When clover was present, nitrogen fertilization decreased the average percentage nitrogen content of the herbage and the yields of nitrogen were slightly lower than where no nitrogen was applied.

DEKALB SILT LOAM

As was stated earlier, the vegetation on the Dekalb soil was largely native grasses and weeds at the beginning of the experiment. Under the clipping conditions the percentage of grasses decreased on the untreated plots, while the percentage of weeds and bare space increased. On the P-K-L plots the percentage of white clover increased rapidly during the summer and fall of the second year so that by the fall of 1931 there was about a 15% stand (Table 4). The application of 100 pounds per acre of nitrate of soda in the spring had no significant effect on the percentage of clover, probably partly because most of the response occurred before any appreciable amount of clover appeared on the area. The plots that received a summer application of nitrogen on June 18 averaged 8% white clover in the fall of 1931. The following spring the clipped herbage from all limed and fertilized plots contained a high percentage of white clover. Clover was also abundant during 1933, except in the early spring. It is interesting to note, as shown in Table 4, that in the fall of 1933 a good stand of clover was present even on the plots that received a heavy application of nitrogen fertilizer. These estimates were not made, however, until three months after the last application of nitrogen. This partly explains the high percentage of clover on the high-nitrogen plots. Nevertheless, the high-nitrogen treatment did not suppress the clover as much on this area as on the Huntington soil, where the clover was competing

TABLE 4.—*The estimated percentages of white clover on various plots on the Dekalb silt loam.**

Date of estimate	Percentage white clover on plots receiving different treatments				
	None	P-K-L	½N-P-K-L	N-P-K-L†	2N-P-K-L†
Sept. 11, 1931	1	15	14	6	10
June 21, 1933	1	6	9	5	6
Sept. 29, 1933	2	35	41	27	25

*All treatments in quadruplicate. See Table 2 for description of treatments.
†The summer application of nitrogen to these plots was made on June 18 in 1931 and on June 29 in 1933.

with a good stand of Kentucky bluegrass. Clover was also abundant in the early spring of 1934, but during the remainder of the season and also during 1935 and 1936 clover was present in only very small amounts.

With increased amounts of available nitrogen, either from nitrogen fertilizer or from the associated growth of white clover, the percentage of Kentucky bluegrass increased rapidly from 1931 to 1933. Since there was no appreciable amount of clover until the second year, the nitrogen-treated plots developed a sod of Kentucky bluegrass somewhat quicker than the no-nitrogen plots. Thus, in the spring of 1932, the P-K-L plots averaged 15% Kentucky bluegrass as compared with 25% on the plots that received nitrogen in addition to P-K-L. The unfertilized plots averaged 5%. By the fall of 1933 excellent stands of bluegrass and clover were established on all limed and fertilized plots. During 1934 to 1936, with but little clover on the area, the percentage of Kentucky bluegrass decreased somewhat, particularly where no nitrogen was applied. In 1936 the estimated stand of bluegrass averaged 40, 50, 60, and 60%, respectively, for the P-K-L, ½N-P-K-L, N-P-K-L, and 2N-P-K-L treatments.

The response to fertilization and the percentage nitrogen recovery on the Dekalb silt loam are summarized in Table 5. The summer and

TABLE 5.—*Summary of the response to nitrogen fertilization on the Dekalb silt loam.**

Plot treatment†	1930	1931	1932	1933	1935	1936	Average
			Yield of Herbage, Lbs. per Acre				
None	763	894	788	435	493	473	641
P-K-L	922	1,771	1,708	1,771	1,037	562	1,295
½N-P-K-L	1,002	1,924	1,903	2,179	1,097	642	1,458
N-P-K-L	1,234	2,243	1,747	1,889	1,261	746	1,520
2N-P-K-L	1,308	2,472	1,935	2,519	1,235	925	1,732
			Nitrogen Content of Herbage, %				
None	2.20	2.05	1.94	1.91	1.65	1.71	1.91
P-K-L	2.11	2.32	3.02	2.90	1.99	2.14	2.41
½N-P-K-L	2.35	2.32	3.18	3.03	2.21	2.31	2.57
N-P-K-L	2.41	2.21	2.61	2.79	2.16	2.35	2.42
2N-P-K-L	2.64	2.32	3.00	2.95	2.40	2.49	2.63
			Yield of Nitrogen, Lbs. per Acre				
None	16.8	18.3	15.3	8.3	8.1	8.1	12.5
P-K-L	19.5	41.1	51.5	51.3	20.6	12.0	32.7
½N-P-K-L	23.5	44.6	60.6	66.0	24.2	14.8	38.9
N-P-K-L	29.7	49.6	45.6	52.7	27.3	17.5	37.1
2N-P-K-L	34.5	57.3	58.0	74.3	29.7	23.0	46.1
			Nitrogen Recovery, %				
½N-P-K-L	25	22	57	92	22	17	39
N-P-K-L	32	27	−18	4	21	17	14
2N-P-K-L	23	25	10	36	14	17	21

*The nitrogen content of the herbage was not determined for the 1934 season.
†All treatments in quadruplicate. See Table 2 for description of treatments.

fall of 1930 were very dry so that most of the season's growth was made in the spring and probably before the lime and superphosphate had penetrated into the soil sufficiently to have much beneficial effect. The P-K-L treatment gave a 21% increase in yield of herbage but averaged slightly lower in percentage nitrogen content than the untreated plots. The response to nitrogen fertilizer in 1930 was similar to the response on the Huntington soil in that marked increases occurred both in yield and in percentage nitrogen content of the herbage. Moreover, the increases in yield of nitrogen from nitrogen fertilization were approximately the same as the increases during the same year on the Huntington soil.

In 1931 marked increases in yield of herbage were shown, both from P-K-L and from nitrogen, but nitrogen fertilization gave no increase in the percentage nitrogen content of the herbage. This is attributed to favorable growing conditions and to infrequent cuttings. Thus, the nitrogen absorbed by the plants, both from the spring and from the summer applications of nitrogen, was used almost entirely for increased growth. In the second cuttings following the nitrogen applications no increase occurred either in yield of herbage or in percentage nitrogen content. In the last cutting the herbage from the P-K-L and the ½N-P-K-L plots was slightly higher in percentage nitrogen than that from the plots which received a summer application of nitrogen. This was due to the higher percentage of clover on these plots.

During 1932 and 1933, the P-K-L plots, which contained a high percentage of white clover, gave a very marked increase over the untreated plots, both in nitrogen content of the herbage and in yield of nitrogen. The effect of the nitrogen fertilizer during those two years depended upon the amounts of nitrogen applied. The ½N treatment, which had increased the percentage of Kentucky bluegrass without reducing the percentage of clover, gave a slight increase in the nitrogen content of the herbage and a somewhat greater increase in yield of herbage and of nitrogen. Since the N treatment decreased the percentage of clover, it resulted in a decrease in the percentage nitrogen content of the herbage. The yields of both herbage and nitrogen were lower on the N than on the ½N and the no-nitrogen plots. The 2N treatment also decreased the percentage of clover, but the nitrogen fertilizer increased the nitrogen content of the nonlegumes enough to compensate for the decrease in clover. Since this treatment increased the yield of herbage, the yield of nitrogen was increased, especially in 1933.

Although there was but little clover on any of the plots during 1935 and 1936, the herbage from the P-K-L plots was considerably higher in percentage nitrogen than that from the untreated plots. Undoubtedly this difference can be attributed partly to the difference in the botanical composition of the plots. The herbage from the untreated plots contained a higher percentage of poverty grass and a much lower percentage of Kentucky bluegrass than the herbage from the P-K-L plots. Earlier studies showed that the total nitrogen content of poverty grass was only 74% as high as that of Kentucky bluegrass growing in association with it (9). In addition, there probably

was some residual effect in 1935 and 1936 from the clover on the P-K-L plots during previous years. Nitrogen fertilizer in addition to P-K-L increased the nitrogen content of the herbage as well as the yield of herbage, both in 1935 and 1936, but since the growth was rather poor, the yield of nitrogen was relatively low.

The percentage nitrogen recovery from the various nitrogen treatments during the years when relatively little clover was present (1930, 1931, 1935, and 1936) ranged from 14 to 32.

It is of interest to note that for the two years when clover was abundant (1932 and 1933) the values for percentage nitrogen recovery were different for the various nitrogen treatments. With the ½N treatment the percentage recovery was higher than during any other year, whereas with the N treatment the recovery was lower than during any other year. As was stated earlier, these results are attributed to the differential effect of the nitrogen treatments on the botanical composition. The ½N treatment increased the percentage of Kentucky bluegrass without depressing the clover, whereas the N treatment very materially depressed the percentage of clover. The 2N treatment also decreased the percentage of clover but with the high rate of nitrogen fertilization the yield of nonlegumes was great enough to compensate for the reduction in the percentage stand of clover.

DISCUSSION

It appears from the results obtained in this investigation that the value of summer applications of nitrogen as compared with spring applications may have been underestimated in the eastern part of this country. The main reason for this is that too often during the summer soil moisture rather than nitrogen is the principal limiting factor in the growth of pastures. In this experiment, however, the total yields over the 7-year period were about as high where part of the nitrogen was applied during the summer as where all of it was applied in the spring. Moreover, the seasonal distribution of growth was more desirable.

Thus, it appears that under conditions where nitrogen fertilization is profitable it may be better practice to apply part of the nitrogen during the summer than to apply all of it in the spring. If the season is favorable, summer applications of nitrogen should give much better seasonal distribution of growth, as demonstrated by 3 of the 7 years' results in this experiment. If the season is not favorable, the nitrogen should still be available for growth when conditions do become favorable.

That very little nitrogen is lost from pastures during the winter is also indicated by the data of Prince, *et al.* (10) and of Richardson (11). Prince, *et al.* (10) found that nitrate of soda applied in September or cyanamid applied in November was about equal to a March application. Richardson (11) reported that, "a late autumn application of nitrogen was almost as effective as a spring one." The data of Evans, Welton, and Salter (3) show that over a 4-year period spring applications of nitrogen to timothy gave higher average yields than fall applications, but the differences were rather small. With 200 pounds

per acre of nitrate of soda applied October 1, the yield of timothy averaged 3,893 pounds as compared with 4,091 pounds where the nitrogen was applied March 15. The corresponding yields obtained where nitrogen was applied April 1, April 15, and May 1 averaged 3,956, 4,117, and 3,955 pounds, respectively. The no-nitrogen plots averaged 2,573 pounds.

Gardner, *et al.* (5), in a progress report stated that, in general, summer applications of nitrogen were not satisfactory because of unfavorable weather conditions. It is interesting to note, however, that over the 5-year period the total yields, both from grazing and from clipping, averaged slightly higher from applying half of the nitrogen in the summer than from applying all of it in the spring. The Kentucky Agricultural Experiment Station (6) reported that, "an application of 300 pounds of nitrate of soda in the latter half of the calendar year again produced better sod and larger growth than applications in the first half."

Brown and Munsell (1), on the other hand, found that over a 4-year period summer applications of nitrogen were not as effective, based on total yields, as spring applications. They also found that under the conditions of their experiments the summer applications of nitrogen decreased the percentage of clover more than did spring applications of nitrogen. Thus the smaller yields from summer applications of nitrogen than from spring applications may have been an indirect effect resulting from differences in percentage of white clover.

Since white clover is an important factor determining the response to nitrogen fertilization, and since the amount of white clover often varies greatly from year to year, any program of nitrogen fertilization necessarily must be flexible.

Where economic conditions justify intensive pasture management, the number of applications as well as the total amount of nitrogen that could profitably be applied during the summer would depend to a large extent upon the season. Obviously, there would be no justification for a second application of nitrogen if the season were so dry that no response had been obtained from the previous application. During a favorable season several summer applications of nitrogen might be most profitable.

The percentage of fertilizer nitrogen recovered in the herbage is rather closely correlated with the increases in yield of herbage from nitrogen fertilization. The more favorable the season, other factors being equal, the higher the percentage nitrogen recovery. On irrigated plots, Mortimer and Ahlgren (7) obtained an average nitrogen recovery of 87.6% from the use of 680 to 1,160 pounds per acre of sulfate of ammonia on a Kentucky bluegrass sod.

Dodd (2) obtained well over 100% nitrogen recovery over a 5-year period from the use of 60 pounds per acre of nitrogen per year. On other areas, however, and with less favorable years, he obtained from 33 to 59% nitrogen recovery.

Munsell and Brown (8) determined the percentage nitrogen recovery from various nitrogen carriers applied at different rates and at different times to Kentucky bluegrass and Rhode Island bent grass. They obtained an average recovery of 46%.

Fagan and Davies (4) reported 129% recovery of nitrogen from a soil very high in organic matter. Under those conditions they attributed the high recovery to the effect of the nitrogen fertilizer in accelerating the decomposition of the organic matter of the soil.

Richardson (11) found that different nitrogen carriers applied at different times on recently established pastures gave at best less than 40% recovery. He suggested that the low recovery may have resulted from the tendency of young grassland soils to increase their nitrogen content. This would likewise appear to be an important factor in determining nitrogen recovery from old unproductive pastures.

In the present investigation conducted on old established pastures, the average value for percentage nitrogen recovery was 23, but the range for different years and for different rates of nitrogen fertilization was from plus 92 to minus 51. The value of minus 51 is, of course, only an apparent decrease. Actually, fertilizer nitrogen was recovered in the herbage but less nitrogen was fixed symbiotically than on the plots receiving no nitrogen. In general, the highest percentage recovery will be obtained during years when growing conditions are most favorable and when legumes are absent.

SUMMARY AND CONCLUSIONS

Studies were conducted over a 7-year period of the effect of nitrogen fertilizers on the yield, seasonal distribution of yield, and percentage of the fertilizer nitrogen recovered in the herbage from clipped plots in permanent pastures.

Although summer applications of nitrogen did not give satisfactory increases in yield during the summer unless soil moisture was adequate, the plots that received part of the nitrogen during the summer produced about the same total yield during the 7-year period as the plots that received all of the nitrogen in the spring. This favorable response to summer applications of nitrogen was obtained at each of two rates, namely, 100 and 200 pounds of nitrate of soda per acre per year. These results indicate that summer applications of nitrogen may have a definite place in a program of intensive dairying. During favorable summers, the nitrogen would help to maintain uniform pasture during the season. During unfavorable years, the effect of the nitrogen would be carried over until growing conditions became more favorable.

The values for percentage nitrogen recovery ranged from plus 92 to minus 51, with an average of 21 for one pasture and 25 for another. These differences were discussed in relation to the season, the botanical compostion of the pasture, and the fertility level of the soil.

LITERATURE CITED

1. BROWN, B. A., and MUNSELL, R. I. Pasture investigations (eighth report): Modifying the seasonal growth habits of grasses. Storrs (Conn.) Agr. Exp. Sta. Bul. 209. 1936.
2. DODD, D. R. The place of nitrogen fertilizers in a pasture fertilization program. Jour. Amer. Soc. Agron., 27:853–862. 1935.
3. EVANS, MORGAN W., WELTON, F. A., and SALTER, R. M. Timothy culture. Ohio Agr. Exp. Sta. Bul. 603. 1939.

4. FAGAN, T. W., and DAVIES, R. O. The recovery of nitrogen in pastures from the application of nitrogenous fertilizers. III. The recovery of nitrogen in swards under the Warmbold system. Welsh Jour. Agr., 10:190-196. 1934.
5. GARDNER, F. D., *et al.* Pasture fertilization. Pa. Agr. Exp. Sta. Bul. 323. 1935.
6. KENTUCKY AGRICULTURAL EXPERIMENT STATION. Forty-ninth Annual Report: 37. 1936.
7. MORTIMER, G. B., and AHLGREN, H. L. Influence of fertilization, irrigation, and stage and height of cutting on yield and composition of Kentucky bluegrass (*Poa pratensis* L.). Jour. Amer. Soc. Agron., 28:515-533. 1936.
8. MUNSELL, R. I., and BROWN, B. A. The nitrogen content of grasses as influenced by kind, frequency of application, and amount of nitrogenous fertilizer. Jour. Amer. Soc. Agron., 31:388-398. 1939.
9. PIERRE, W. H., and ROBINSON, R. R. The calcium and phosphorus content of pasture herbage and of various pasture species as affected by fertilization and liming. Jour. Amer. Soc. Agron., 29:477-497. 1937.
10. PRINCE, F. S., PHILLIPS, T. G., BLOOD, P. T., and PERCIVAL, G. P. Experiments with grass hay. N. H. Agr. Exp. Sta. Bul. 306. 1938.
11. RICHARDSON, H. L. Calcium cyanamide. IV. Use of cyanamide and other forms of nitrogen on grassland. Jour. Agr. Sci., 24:491-510. 1934.
12. ROBINSON, R. R., and PIERRE, W. H. Response of permanent pastures to lime and fertilizers (1930-1936). W. Va. Agr. Exp. Sta. Bul. 289. 1938.

THE CHEMICAL COMPOSITION, GROWTH, AND CERTAIN DEFICIENCY SYMPTOMS OF CARPET GRASS, *AXONOPUS AFFINIS*, AS AFFECTED BY LIME AND FERTILIZER MIXTURES[1]

R. E. BLASER AND W. E. STOKES[2]

CARPET grass grows especially well on the moist Coastal Plain soils of the Southeast. It thrives under lower fertility levels than Bermuda, Dallis, and other improved pasture grasses commonly grown in the South. Over 400,000 acres of carpet grass have been planted for pasture in Florida during the last three years.

Although carpet grass is not generally fertilized, it has been thought for some time that fertilization would improve growth to a profitable extent. Experiments were laid out in 1937 to study the effect of rates and mixtures of lime and fertilizers on growth and chemical composition of carpet grass. Certain deficiency symptoms which became conspicuous four years after the experiment was initiated are given in this paper.

EXPERIMENTAL METHODS

Carpet grass growing on a virgin Bladen fine sand (pH 4.92 and 3.78% organic matter) was fertilized with various rates and combinations of lime and fertilizers during March 1937. Lime and fertilizer formulae were applied on plots 7 × 25 feet in randomized blocks replicated four times. The mixtures were weighed for each plot, then surface broadcast by hand in March 1937.

Yield estimates of grass were taken by mowing a 25-inch strip through the center of each plot with a special lawn type power mower equipped with a box to catch the clippings. After the plots were sampled for yields, the borders were clipped. Single analyses for various minerals were made of plants from three of the replicated plots samples on May 9, 1940. The total yields for three clippings taken during the period of April 17 through May 28 are given.

EXPERIMENTAL RESULTS

Clippings of unfertilized carpet grass averaged 0.355% calcium, 0.134% phosphorus, 0.640% potassium, and 1.869% nitrogen, as compared to 0.573% calcium, 0.234% phosphorus, 0.794% potassium, and 1.904% nitrogen when fertilized with lime and complete fertilizer (Table 1). The differences in calcium and phosphorus are highly significant, those of potassium significant.[3] The growth stage of any grass influences the mineral content greatly.[4] Since nitrogen

[1]Contribution from the Department of Agronomy, Florida Agricultural Experiment Station, Gainesville, Fla. Published with the permission of the Director. Received for publication May 14, 1942.

[2]Associate Agronomist and Agronomist and Head of Department, respectively. Assistance in computations by Jeffery Dawson, chemical analysis by the Agronomy Biochemical Laboratory, and soil analysis by the Soils Department are gratefully acknowledged.

[3]Hereafter "significant" refers to $P = .05$ and "highly significant" to $P = .01$.

[4]LEUKEL, W. A., CAMP, J. P., and COLEMAN, J. M. Fla. Agr. Exp. Sta. Bul. 269, 1934.

content is one of the best criteria for estimating the growth stage of forage plants, and because the differences in nitrogen content of fertilized and unfertilized carpet grass are not significant, the differences in mineral content are therefore attributed to fertilization.

TABLE 1.—*Chemical composition and yield of carpet grass as influenced by lime and fertilizer mixtures on a bladen fine sand.*

Lime and fertilizer, pounds per acre*				Composition on dry and sand-free basis				Dry yield per acre†
Lime	N	P_2O_5	K_2O	Ca, %	P, %	K, %	N, %	
0	0	0	0	0.355	0.134	0.640	1.869	136
2,000	72	144	100	0.573	0.234	0.794	1.904	1,058
0	72	144	100	0.395	0.161	0.667	1.918	743
2,000	72	0	200	0.254	0.107	0.874	1.915	628
2,000	72	144	0	0.395	0.174	0.401	1.910	638
Least significant difference P=.05				0.051	0.012	0.147	‡	189
P=.01				0.070	0.016	0.203	‡	251

*Ground calcic limestone, N, P_2O_5, and K_2O given in total pounds per acre applied during 4-year period. N (50/50 mixture of nitrate of soda and sulfate of ammonia) was applied annually in two applications.
†Dry yields are means of three clippings (April 17, May 9, and May 28, 1940). Chemical analyses were made from clippings taken on May 9, 1940.
‡Not significant according to "F" test.

The early season yield of unfertilized grass was 136 pounds (oven-dry) as compared to 1,058 pounds per acre when the grass was fertilized with lime and complete fertilizer. When potassium or phosphate was omitted from the lime and fertilizer mixture, the resulting grass yields were significantly lower.

Carpet grass plants growing on plots fertilized with lime, potassium, and nitrogen were dull green to purplish green in color, due to the absence of phosphorus (Fig. 1). Plant analysis revealed that the phosphorus content of grass treated with lime, nitrogen, and potassium was 0.107% as compared to 0.234% when phosphorus fertilizer was supplied. These differences are highly significant and substantiate the phosphorus deficiency symptoms. Without fertilization, carpet grass blades were yellowish green with a purple tint due to a nitrogen and phosphorus deficiency, respectively. It is apparent that phosphate deficiency symptoms differ considerably, depending on the presence or absence of other nutritive elements. Similar differences in phosphorus deficiency symptoms as affected by the presence or absence of other nutritive elements have been reported for lespedeza.[5]

Potassium deficiency symptoms (a burning or browning of tips of blades) of carpet grass occurred on plots treated with lime, nitrogen, and phosphorus (Fig. 2). Normal growth resulted when potassium was supplied. The potassium content of carpet grass plants receiving

[5]BLASER, R. E., VOLK, G. M., and STOKES, W. E. Composition and deficiency symptoms of lespedezas as related to lime and fertilizer mixtures. Jour. Amer. Soc. Agron., 34:222–228. 1942.

complete fertilizer and lime averaged 0.794% as compared to .401% when potassium fertilizer was omitted. This highly significant difference in potassium content of deficient and normal plants substantiates the potassium deficiency symptoms.

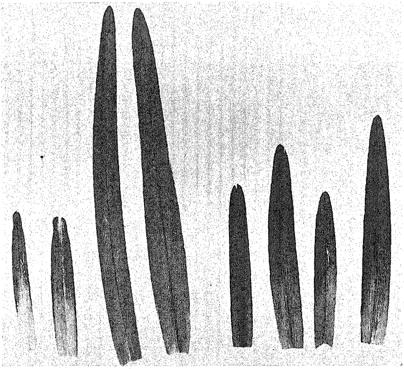


FIG. 1.—Phosphorus deficiency symptoms of carpet grass. *Center* (two large blades), normal blades of carpet grass treated with lime and complete fertilizer. *Right* (four blades), blades of carpet grass taken from plants where phosphorus was omitted from the lime and fertilizer mixture. These blades varied from a dull dark green to purplish color. Some blades, as the one on the left, were distinctly purple. Purplish colorations started at the apex and developed toward the base of the blades. *Left* (two blades), phosphorus-deficiency symptoms of two blades taken from unfertilized plants. The yellowish color of these blades is a result of insufficient nitrogen. The purplish color near the blade tips was due to insufficient phosphorus. Blades from plants fertilized with phosphorus and potassium (not shown) were yellowish due to low soil nitrogen, but the purplish color was absent.

The calcium content of carpet grass fertilized with lime and complete fertilizer averaged 0.573% as compared to 0.395% when complete fertilizer was supplied without lime. Although these differences in calcium content are highly significant, no abnormal growth condition was observed for the low calcium plants.

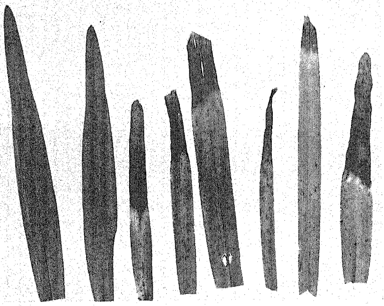


FIG. 2.—Potassium deficiency symptoms of carpet grass. *Left* (two blades), normal blades from plants treated with lime and a complete fertilizer. *Right* (six blades), potassium-deficiency symptoms of carpet grass blades when potassium fertilizer was omitted. Typical deficiency symptoms show a burning of tip of blades and often yellowish colorations of the midrib.

SUMMARY AND CONCLUSIONS

The calcium, phosphorus, and potassium content and the growth of carpet grass grown on a Coastal Plain soil (Bladen fine sand) was significantly better with a top dressing of lime and complete fertilizer than with no fertilizer.

The omission of lime, phosphorus, or potash from the fertilizer treatment produced carpet grass which was significantly lower in calcium, phosphorus, or potassium, respectively. The omission of any one of these three fertilizer elements also resulted in significant grass yield reductions.

When phosphorus was omitted from the lime and fertilizer mixture, the carpet grass was dull green to purplish green in color, and it is believed that this is characteristic of phosphorus deficiency. Phosphorus-deficiency symptoms also occurred without fertilizer, but the presence of calcium, potassium, and nitrogen altered the phosphorus-deficiency symptoms when compared with unfertilized grass.

Potassium-deficiency symptoms (burning of blade tips) were present when potassium fertilizer was omitted from the lime and fertilizer treatment.

Bladen fine sand is deficient in phosphorus, nitrogen, potassium, and calcium. The relative importance of the elements is approximated by the order in which they are given.

NOTES

A SURVEY OF BIOLOGICAL DESTRUCTION OF CACTUS ON NEBRASKA RANGE LAND

WHILE making some range studies in the hardlands and sandhills near Valentine, Nebr., in the summer of 1941, it was observed that cacti (*Opuntia humifusa* and *O. fragilis*) were being destroyed by a caterpillar. In view of the fact that biological control of cactus has not been considered important in this area, it was decided to determine the amount of cactus that was being destroyed. The caterpillars were identified by the Department of Entomology, University of Nebraska, as *Melitara* sp., tentatively designated *dentata*. The density was recorded by the square foot density method (Stewart and Hutchings 1936). Destruction was estimated as the percentage of dead cactus. Notes were made of observations in various pastures and reserved areas.

An average of 90 plots, 100 square feet in size, in nine study areas in the sandhills showed a density of 0.103 square feet of cactus per 100 square feet of ground surface with 49.78% destruction. On an acre (43,560 square feet) basis this would be 44.87 square feet of cactus with 22.34 square feet destroyed. An average of 100 plots in 10 study areas in the hardlands showed a density of 0.144 square feet of cactus per 100 square feet of ground surface with 29.85% destruction. On an acre basis this would be 62.90 square feet of cactus with 18.78 square feet destroyed. The figures would indicate that the spread of cactus in the areas studied is being effectively controlled by the cactus caterpillar.

A small tract of land about 5 acres in size lies on the eastern edge of Valentine. This tract had previously been heavily grazed until cactus (principally *Opuntia fragilis*) became so abundant that grazing was almost impossible and consequently was discontinued. Blue grama (*Bouteloua gracilis*) had produced a good sod, and on the ground was a layer of cactus 60 to 75% of which was destroyed. Another small area about 1 acre in size was located in the Fort Niobrara Game Preserve. This area, which was dominated by wheatgrass (*Agropyron smithii*), had been closed to grazing for several years. Several large colonies of cactus (chiefly *Opuntia humifusa*) were from 80 to 100% destroyed. Several heavily grazed blue grama pastures were observed in which cactus was quite abundant. It was also observed that the cactus in these pastures had not been infested to a very great extent with the cactus caterpillar.

Cactus although present in the sandhills never has been a serious problem, whereas in the hardlands it often becomes so. The sandhills have a tall-grass vegetation and the hardlands have a short-grass vegetation. Therefore, the tall-grass habitat studied seems to be more favorable for the development of the insect than the short-grass habitat. Considering the hardland data, where it is shown that heavily grazed pastures may not be infested at all as compared to almost complete destruction in reserved areas, it seems that the height of the grass may have an indirect effect on the activity of the

cactus caterpillar. Since very little activity by the insect was observed by other investigators during the previous 3 years, weather conditions may exert considerable influence on its activity. The ecology of this insect has not been worked out for this area, but the evidence presented would indicate that the activity of the cactus caterpillar should be taken into consideration in range management of short-grass vegetation in this area.—M. W. PEDERSEN, *Department of Agronomy, Nebraska Experiment Station, Lincoln, Nebr.*

BROMEGRASS TOXICITY VS. NITROGEN STARVATION[1]

THE so-called "sod-bound" condition in bromegrass fields has been recognized by agriculturists for many years. The condition is especially serious on those fields used for seed production but is also a factor in lowering the carrying capacity of recently established pastures. For several years in Kansas this condition has been thought to be associated with a deficiency of available nitrogen since it had been shown both experimentally and by farm practice that nitrogen either in the form of commercial fertilizers, animal urine, or legumes improved the growth of bromegrass in an otherwise "sod-bound" field. The "sod-bound" condition is not peculiar to bromegrass alone but has been observed in other tame grasses and in native grasses when they were long established on cultivated areas.

The recent note by Benedict[2] offering evidence, that a toxic substance produced by the growing or decomposing bromegrass roots, was responsible for the "sod-bound" condition stimulated additional investigations.

The areas selected for study were three fields lying in adjacent strips on the farm of A. M. Brunson located on a highly fertile silty clay loam, a terrace soil in the Kansas River valley. On one area bromegrass had been established in the fall of 1937. On the second area the bromegrass had been established in the fall of 1939. The third area has never grown bromegrass. It had been in annual non-legume crops for several years and had produced a wheat crop in 1941. The bromegrass areas were used both for early spring pasture and for the production of seed. The maximum seed yield, according to the farm records, was obtained the second year after the sod was established, following which the seed yield dropped rapidly.

During the year 1941 the sod established in 1937 was obviously "sod-bound". The seed production was so low that only a part of the area was harvested. The seed yields for 1939 and 1940 were about 400 and 150 pounds per acre, respectively. In the early spring of 1941 the grass showed evidence of nitrogen deficiency and the cattle for the most part refused to graze on this portion of the pasture but stayed mostly on the area established in 1939. The sod established in 1939 showed no distinct evidence of a "sod-bound" condition in the spring of 1941.

[1]Contribution No. 336 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans.

[2]BENEDICT, H. M. The inhibiting effect of dead roots on the growth of bromegrass. Jour. Amer. Soc. Agron., 33:1108–1109. 1941.

For a greenhouse study, surface soil to a depth of about 6 inches was removed during December 1941 from each of the three areas and put through a ¼-inch screen. The root material removed as a result of screening was cut into lengths of about ¼ inch and returned to the soil. The soil from a given field was then carefully mixed and equal weights put into wooden flats about 18 inches square and 5 inches deep. The plantings for each of these three soils consisted of (a) pure seedings of bromegrass; (b) alternate rows of bromegrass and alfalfa; (c) randomized rows of pure stands of six grasses including bromegrass, meadow fescue, orchard, Kentucky bluegrass, red top, and timothy; and (d) alternate rows of alfalfa with the above grasses. All seedings were made in rows, 11 per flat. Alfalfa was seeded in one-third of the flats. All species were seeded at a rate sufficient to insure a heavy stand and subsequently thinned to a uniform number of plants per row. One-half of those without alfalfa received the equivalent of 200 pounds of ammonium sulfate per acre after the grasses became established. The alfalfa developed so rapidly and abundantly that the grasses did not have a chance to develop satisfactorily. The early growth of alfalfa on the three soils showed distinct differences. Damping-off of seedlings was serious on the cultivated and the 1939 bromegrass soil. In contrast to this the soil that had become decidedly "sod-bound" was practically free of damage from damping-off. This would suggest that the microbial flora of the soil had been changed as a result of the prior growth of bromegrass. The differences are recorded photographically in Fig. 1.

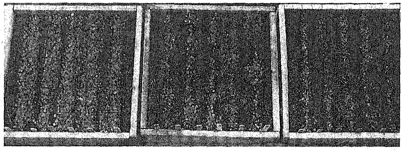


FIG. 1.—Effect of previous growth of bromegrass on damping-off in alfalfa seedlings. *Left,* flat grown in soil from 4-year old brome sod; *center,* flat in soil from 2-year old sod; and *right,* flat in soil from a cultivated field that had not previously grown brome. Photo taken approximately 6 weeks after seeding.

The emergence and early development of the grasses were more rapid in those soils that previously grew bromegrass than on the cultivated soil. A greater number of seedlings emerged in the bromegrass soil. This difference was possibly associated with the physical properties of the soils since the cultivated soil crusted much more easily than did those that had grown bromegrass.

On the unfertilized soil the mixture of grasses behaved in a manner similar to the pure stand of bromegrass. The grasses were more vigorous on the unfertilized cultivated soil than on either of the unferti-

lized soils that had grown bromegrass. In appearance there was not much difference between the grasses on the two sod soils. In both instances the grasses were pale green and lacking in vigor, indicating an unhealthy condition that might be attributed, according to Benedict, to a toxic material resulting from the previous bromegrass. (See Fig. 2.) This was true of all grasses, which suggests that if a bromegrass toxin were present it was toxic to all species used in the study.

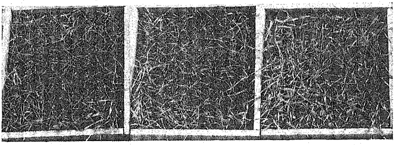


FIG. 2.—Effect of "sod-binding" on growth of bromegrass seedlings grown in soil taken from 4-year old bromegrass sod (left), from 2-year old bromegrass sod (center), and from an adjacent cultivated field (right) which had never grown brome. Photo taken approximately 2½ months after planting.

After a growth period of about 4 months the grasses were clipped and total oven-dry weight per flat determined. The results are shown in Table 1.

TABLE 1.—*The effect of bromegrass sod with and without nitrogen fertilizer on the yield of grasses.*

Previous crop	Average yield of all grasses (N = 4), grams*	
	Unfertilized	Ammonium sulfate 200 lbs. per acre
Bromegrass, 4 years	28.2	38.2
Bromegrass, 2 years	25.0	39.8
Wheat (no bromegrass)	35.1	53.7

*Oven-dry weights.

The response from the 200 pounds of ammonium sulfate was distinct on all three soils. A comparison of the fertilized bromegrass soils with the unfertilized cultivated soil shows that the 200 pounds of ammonium sulfate permitted even greater growth in these soils than in the soil that had not grown bromegrass but left unfertilized.

Soon after the fertilizer was applied it appeared that the older sod was not going to show as marked a response as the newer sod. However, after a few weeks the nitrogen response on the older sod became relatively greater. By the time the seedlings were 3 months old there was practically no difference between the two fertilized sod soils.

On the basis of the results obtained in this experiment, there appears to be no positive evidence to indicate that a toxic constituent

was produced by the bromegrass, since 200 pounds of ammonium sulfate more than overcame any detrimental effect that the previous growth of bromegrass had on subsequent grass production. If a toxin were produced the ammonium sulfate either destroyed it directly or indirectly, neutralized it, or gave to the plants power to resist the detrimental toxic material.

Our knowledge of the effect of carbonaceous material on the availability of plant nutrients, more commonly nitrogen, as the result of the activities of soil organisms, leads to the generalization that excessive carbon in relation to nitrogen brought about by the continued growth of bromegrass probably caused the so-called "sod-bound" soil in the field under consideration. The rapid destruction of almost any compound of energy value to microbes under proper nutrient and environmental conditions was demonstrated by Robbins[3] when the usage of the term "toxin" in soils was in its infancy. These facts, together with the results from applying nitrogen fertilizer to the soils under test, suggests that a search should be made for deficiencies in soil fertility as possible causal factors responsible for "sod-bound" conditions observed under a variety of soil conditions. —H. E. MYERS and KLING L. ANDERSON, *Kansas Agricultural Experiment Station, Manhattan, Kan.*

"SOLF" AND "SEEDSOLF", SUGGESTED TERMS TO DESIGNATE CERTAIN MIXTURES OF MATERIALS

IN the April issue of this JOURNAL, F. V. Grau proposed the term "FLOSS" for a mixture of fertilizer, lime, organic matter, soil, and seed for use in repairing breaks in golf, lawn, and polo turfs, and in seeding sloping banks. He has used the term elsewhere in print (Greenkeeper's Reporter, 10(3):39. May-June, 1942).

There are several objections to this proposal. First, the word "floss" has another old and well-known meaning and it seems quite undesirable, as well as difficult, to give an old word a new and quite different meaning. English already is sufficiently difficult. Secondly, it was proposed that the new term always be written and printed in capital letters (FLOSS) in order to distinguish it instantly from the same word (floss) of older and different meaning. This not only is undesirable practice, but it would be practically impossible to accomplish. The proposal to capitalize the letters, in order to indicate a different meaning, introduces an entirely new and undesirable principle in language construction. Then, too, one cannot speak capitals, and how could the word be capitalized again in a title or heading already written in capital letters? The present tendency in English is toward fewer capital letters, even as initials, and it seems unlikely that writers and printers consistently would put a whole word in capital letters simply to indicate a special meaning.

In the third place, the letters in the proposed word "floss" are not in the order in which the ingredients normally would be taken. Surely one would start with soil and end with seed, no matter in what order

[3]ROBBINS, WILLIAM J. The destruction of vanillin in the soil by the action of soil bacteria. Ala. Agr. Exp. Sta. Bul. 204. 1918.

the other three were added. Also, if the four ingredients other than seed were mixed together and applied as a plaster to broken or ungrassed surfaces, this mixture would have no name at all. Finally, no mention is made of the use of water in this mixture. Its use would provide another initial, "w", to be inserted in a proposed name.

It is by no means certain that a name is needed for mixtures of this nature. But a name has been proposed and is being used by its author in printed material. Some thought should be given, therefore, to a really suitable term. It would have been helpful if the original proposal could have been considered by specialists before publication. The present paper was submitted to experts in the Bureau of Plant Industry and the Greens Section of the U. S. Golf Association.

If a name is needed, a natural order in which these five ingredients might be taken is as follows: Soil, organic matter, lime, fertilizer, and seed. Using the initials of these five ingredients in that order, we find ourselves with the word "solfs". This is an entirely new word but, although it would be a singular noun, it unfortunately has the plural form and would be confusing.

It is suggested that the mixture of the first four ingredients, soil, organic matter, lime, and fertilizer, be designed by the term "solf", formed from their initials. This permits the plural form, "solfs", to designate different mixtures of these ingredients. Such a mixture is used as a plaster to fill holes in turf where creeping or stolon-bearing grasses, such as creeping bent, bluegrass, etc., are expectd to cover the bare surface through vegetative growth. If water were added, the term "swolf" could be used.

When seeds of grasses and/or legumes are incorporated in the mixture, it would be termed a "seedsolf" (or "seedswolf"). The plural form, to designate different seed mixtures, would be "seedsolfs" or "seedswolfs".—CARLETON R. BALL, *U. S. Dept. of Agriculture, Washington, D. C.*

BOOK REVIEWS

METHODS OF PLANT BREEDING

By Herbert Kendall Hayes and Forrest Rhinehart Immer. New York: McGraw-Hill Book Co. Inc. XII+432 pages, illus. 1942. $4.

THIS book is developed from the subject matter presented by the authors in a course to upper classmen and in courses to graduate students at the University of Minnesota. It is thus primarily a text book. It aims to present standardized methods of breeding for particular categories of breeding problems, and to present the current viewpoint when the most desirable method is not so well known. The advantages and disadvantages and proper use of each of the three principal methods of hybridization are discussed with relation to different crops, namely, the pedigree method of selecting during the segregating generations, the bulk method with self-pollinated plants, and the backcross method and convergent improvement.

The genetics of each crop plant is not completely reviewed, but wheat, oats, barley, flax, and corn are treated fully and serve as

standards to show what should be done by the student or plant breeder who intends to study or hybridize a given crop. Two chapters, totaling 55 pages, are devoted to corn breeding, and serve as a basic pattern for other crops where similar methods are employed.

Exactly 100 pages, or a little over one-fourth of the book, is devoted to statistics, including methods of field plot technic, experimental design, and statistical analysis with particular reference to plant breeding. In an appendix are six useful tables taken from Fisher, Snedecor, and Bliss. A glossary of 9 pages and 20 pages of literature citations complete the book. (H. B. T.)

PLANT LIFE—A TEXTBOOK OF BOTANY

By D. B. Swingle. New York: D. Van Nostrand Co. Inc. Ed. 2. XVI+457 pages, illus. 1942. $3.

FIRST published in 1935 and reprinted in 1938, this is the second and revised edition, brought out by the success of the first. The plan employed in the first edition to treat plants as living things with emphasis on their physiology and behavior is followed in the second edition. The few changes which have been made are still further in this general direction in which more natural history is introduced and some of the other material slightly condensed. The dedication as nearly characterizes the book as anything further that can be said, namely, "To the many naturalists who, since the dawn of civilization have seen plants as living individuals, not as dull objects to be passed by without notice".

A few new illustrations have been added and a few improved substitute illustrations have been employed. The length of the book is about the same as in the first edition and is still intended as a one-semester course. About half of the pages are devoted to living plants, their surroundings, their food, their growth, and their reproduction. The other half deals with groups of plants and their classification. Chapters on the relation of plants to each other and to animals, a very good glossary of technical terms, and a table of singular and plural forms of botanical terms having Latin and Greek endings complete the book. (H. B. T.)

LABORATORY MANUAL FOR STUDENTS IN AGRONOMY

By L. F. Graber and H. L. Ahlgren. St. Louis: Planographed by John S. Swift Co., Inc. Ed. 3. Introduction and Index+155 pages, illus. 1942. $2.

THE 50 exercises included in this manual are intended to be "supplementary to a general survey of plant sciences for college students in which emphasis is placed on the application of biological fundamentals to agronomic practice." To this end exercises are outlined for the study of land utilization and crop distribution in the United States, plant classification, morphology of plants with special emphasis on crop plants, crop identification, crop classification, crop utilization, and heredity. Graphs, maps, and statistics "portray land

utilization, agricultural regions, and crop distribution. * * * * Most of the exercises are provided with drawings and many of them are purposely without the accuracy of complete botanical detail." Agronomic definitions and tables of weights and measures are helpful supplementary information.

This manual is worthy of consideration by every teacher of college agronomy who believes that students should know the elementary botany of farm crops. The difficulties of preparing such a book excuse its few minor defects which consist of an occasional ambiguous sentence and lack of stated subjects for a few of the exercises. Perhaps a definition or two will not be accepted universally. The book is well organized and put up in distinctly usable form and binding.

To use this manual effectively in the elementary agronomy course will not ease the teaching load of the instructor, but it should bring him great satisfaction in his work because the student who understandingly does the work prescribed will have a good foundation in the science of farm crops. (E. N. F.)

AGRONOMIC AFFAIRS

NEWS ITEMS

Doctor W. H. Metzger, Associate Professor of Soils, Kansas State College, died on July 7 at Columbia City, Indiana, after an illness of seven months. At the time of his death Doctor Metzger was on sick leave from Kansas State College.

—A—

Doctor Howard B. Sprague has been granted a leave of absence from his duties as Agronomist at the New Jersey Agricultural Experiment Station to accept a commission as a captain in the Intelligence Division of the Army Air Corps. At present he is stationed at Miami Beach, Florida.

—A—

Doctor Nathan Gammon, Jr., research chemist in the Department of Agronomy, Ohio Agricultural Experiment Station, in cooperation with the Bureau of Plant Industry, U. S. Dept. of Agriculture, has been commissioned an ensign in the Navy Ordnance. He reported for duty July 15 at Dartmouth College for special training.

—A—

Professor James A. Scott Watson, formerly Sibthorpian Professor of Rural Economics at Oxford University and Editor of the Journal of the Royal Agricultural Society, was recently named Agricultural Attaché to the British Embassy at Washington and Agricultural Advisor to the High Commissioner for the United Kingdom in Canada.

JOURNAL
OF THE
American Society of Agronomy

VOL. 34 SEPTEMBER, 1942 NO. 9

AN ADEQUATE SAMPLE OF CORN PLOTS WITH REFERENCE TO MOISTURE AND SHELLING PERCENTAGES[1]

G. F. HENRY, E. E. DOWN, AND W. D. BATEN[2]

THIS paper deals with the results of an investigation carried on at the Michigan Experiment Station to determine the minimum number of ears necessary to sample adequately at harvest time a plot of corn for moisture content of the grain and for shelling percentage.

MATERIAL AND METHODS

Data were gathered on October 18 and 19, 1939, on 10 varieties of corn which were replicated five times.

Each variety was planted in plots 4 by 10 hills (3½ by 3½ feet) and thinned to three plants to a hill. Only one of the central rows in each plot was used in the analyses.

Each ear was labeled with its variety, plot, hill, and plant number at harvest. Each ear was weighed and placed in a drier for 2 days to reduce the moisture content and then reweighed and shelled. The moisture content of the shelled grain was immediately determined by the Steinlite moisture meter. Total moisture was calculated. The shelling percentage of each ear was also calculated.

Two varieties had two missing hills, so the population of all varieties was reduced at random to 8 hills per replication. The values for the moisture content and shelling percentages were analyzed by the analysis of variance. The mean moisture content of the varieties varied from a low of 12.9% to a high of 23.2% with a grand mean of 18.86%. The mean shelling values of the varieties varied from 77.3 to 85.0% with a grand average shelling percentage of 81.85.

MOISTURE CONTROL

The analysis of variance pertaining to moisture content is given in Table 1. Several workers[3] have used formula 1 and ideas underlying

[1]Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich., Journal Article No. 472. Received for publication February 2, 1942.

[2]Former Graduate Assistant, Research Professor in Farm Crops, and Research Associate in Statistics, respectively.

[3]IMMER, F. R. A study of sampling technic with sugar beets. Jour. Agr. Res., 44:633-647. 1932.

YATES, F., and ZACOPANY, I. The estimation of the efficiency of sampling, with special reference to sampling for yield in cereal experiments. Jour. Agr. Sci., 25:545-577. 1935.

SNEDECOR, G. W. Statistical Methods. Ames, Iowa:Collegiate Press.

TABLE 1.—*Analysis of variance of moisture content of corn.*

Source	D.F.	Sum of squares	Mean square
Total	1,168*	23,546.00	—
Replications	4	52.45	—
Varieties	9	11,245.75	1,249.53
Replications × varieties	36	441.15	12.25
Within-plot	1,119*	11,806.65	10.55

*Estimates were made of missing ears and allowance made in the degrees of freedom.

this formula for determining the number of determinations to take from each plot in order to secure a required variance of the mean. This formula is

$$n = \frac{m}{NK - p} \qquad 1$$

where K, N, n, m, and p represent, respectively, the required variance of the mean, the number of replications, the number of units (ears in this case) per plot, the variance between ears within plots, and the variance due to soil differences, i.e., the variance between plots within replications minus the variance within plots expressed on a plot basis

It is not possible to use this formula in our case, for in most of the material pertaining to shelling percentages the experimental mean square (the mean square obtained from the interaction-replication × variety-line in the analysis of variance table) is smaller than the mean square obtained from the within-line in the analysis of variance table. In this case p comes out to be a negative number. This is meaningless, for p is a variance, and it is not possible for a variance to be negative. In some of the material pertaining to moisture content of the corn, when the desired standard deviation of the mean is to be 1% of the grand mean, the value of n, the number of ears to take at random from each plot, comes out to be a negative number, which is absurd. By using the above formula it is possible in some cases to obtain a value for the denominator to be equal to 0. This leads to an indeterminant value for n, the number of ears. This is contrary to good judgment. One might argue that the variance between plots within replications should be larger than the variance within plots, since plots are larger than the units in the plots. In many experiments this is true, but in our data pertaining to moisture content and shelling percentages this was not always true.

Since p and n come out to be negative in several cases, the above formula was not used for determining the number n. The formula which seems appropriate is

$$\sigma \text{ mean} = \frac{\text{Experimental error}}{\sqrt{Nn}} \qquad 2$$

or

$$n = \frac{\text{Error variance}}{NK} \qquad 2A^{4}$$

[4]This is a special case of formula 1 when p = 0.

where N is the number of replications, n is the number of ears to be taken at random from each plot, and K is the required variance of each mean.

Table 2 contains the values of n for various replications and varieties in order that the standard deviation of each mean will be 5% of the general mean, 18.86%, of the moisture contents. Values of n are listed in the body of Table 2 when 7 or 8 hills per plot were used in analyzing the data. The first value in this table is $n = 3$. It was found by substituting $N = 5$, $K = (5\% \text{ of } 18.86)^2 = (0.943)^2 = 0.889$ in formula 2A. This gives

$$n = \frac{12.25 \text{ (Error variance from Table 1)}}{5(0.889)}$$

$$= \frac{12.25}{4.445} = 2.76 \text{ or } n = 3.$$

The other values pertaining to 10 varieties and 8 hills per plot were found by formula 2A by using the same error variance, 12.25%, the same desired variance of the mean, 0.889, and 4, 3, 2, and 1 replications, respectively. Here, it is assumed that the error variance, obtained when 4, 3, 2, and 1 replications are used, will be about the same as when 5 replications are used. Values of n pertaining to nine varieties were obtained from formula 2 and the error variance found by analyzing the data from the first nine varieties, this being obtained from an analysis of variance table similar to Table 1. Values in Table 2 are rounded off to whole numbers. In many cases the numbers are too large, for if 2.03 was obtained from formula 2, 3 was used for n. Formula 1 was used for determining the values of n from moisture content data for numbers of replications from 1 to 5 and for numbers of varieties from 1 to 10. These values were about the same as those found in Table 2.

TABLE 2.—*Number of ears necessary to take at random so that the standard deviation of the mean of the moisture contents of the corn will be 5% of the grand mean of 18.86%.*

No. of varieties	No. of replications				
	5	4	3	2	1
10	3	4	5	7	14
9	3	4	5	8	16
8	3	4	6	8	16
7	3	4	6	8	16
6	4	5	6	9	16
5	4	5	7	10	18
4	4	5	7	10	18
3	4	5	7	10	20
2	4	5	7	10	20
1	4	5	7	10	20

SHELLING PERCENTAGES

The analysis of variance pertaining to shelling percentages is given in Table 3. In this table the replication × variety — mean square is smaller than the within-plot mean square. The value of p used in formula 1 is a negative number. This was true when analyses of variances were carried out for numbers of varieties from 1 to 10 for 5 replications with 8 hills per plot.

TABLE 3.—*Analysis of variance of shelling percentages.*

Source	D.F.	Sum of squares	Mean square
Total	1,168*	22,553	———
Replication	4	104	———
Variety	9	5,654	628
Replication × variety	36	478	13.3
Within-plot	1,119*	16,317	14.6

*Because of missing values.

Table 4 contains the numbers of ears necessary to take from each plot so that the standard deviation of each mean of shelling percentages will be 1% of the grand mean of shelling percentages, 81.85%. Some of these values are too large because every number was made the next largest whole number. For example, if n came out to be 4.06, the value 5 was inserted in Table 4. The results from analyses for number of varieties from 9 to 1 are about the same as those given in this table. The results from all analyses indicate that, on the average, about 20 ears should be analyzed for shelling percentage in order that the standard deviation of the mean of shelling percentages will be as designated above.

TABLE 4.—*Values of n, the numbers of ears to take at random from each plot so that the standard deviation of the mean will be 1% of the grand mean of shelling percentages 81.85%.*

No. of varieties	No. of replications				
	5	4	3	2	1
10	4	5	7	10	20

In order to determine whether or not the values given in Table 2 and Table 4 will lead to the desired standard deviations of the means, sampling was carried out from the original determinations of moisture contents and shelling percentages, together with calculations of analyses of variances and standard deviations of means. For example, 4 ears of corn were taken at random from each plot from 5 replications and 7 varieties. The standard deviation of the mean was found from the experimental error which was obtained from an analysis of variance. In every case the standard deviation of the mean was smaller than the desired value, showing that the values of n are about right.

The number of ears necessary to take at random from each plot so that the standard deviation of the mean of shelling percentages will be 5% of the grand mean, 81.85%, is equal to 1 for replications 2 to 5 and for numbers of varieties 3 to 10 and equal to 2 for 2 replications and for 2 varieties and about 5 ears from 1 variety and 1 replication.

SUMMARY

An experiment was carried out to determine the number of ears necessary for an adequate sample at harvest time of a variety of corn for its moisture content of the grain and for the shelling percentage.

Numbers of ears were found for various replications and varieties.

An adequate sample is a sample such that the standard deviation of the mean of the sample will be at most equal to 5% of the grand mean.

DEGENERATION WITHIN COTTON VARIETIES[1]

J. F. O'Kelly[2]

THAT seed supplies of improved cotton varieties distributed by breeders are not pure lines is generally known. That such seed stocks degenerate, that is, in some way undergo undesirable changes as they are grown year after year, is generally claimed by practical cotton producers. Much of this degeneration has been justly attributed to cross pollination at flowering time and mechanical mixing with other seed stocks at gins, in places of storage, and in other ways.

It is not generally agreed among cotton research workers that improved cotton seed stocks will degenerate materially if cross pollination and mechanical mixing are prevented. It appears obvious that if a cotton variety were a pure line and if harmful mutations did not occur, there would be no degeneration of this kind. It is almost equally obvious that degeneration of this kind must be relatively slight since the combined degeneration from all sources is sometimes difficult to measure from year to year in field trials. This project was undertaken to determine if such degeneration does occur, the nature and rapidity of such degeneration, and to compare two methods of maintenance. That portion of the data covering changes which affect the production, yield, and harvesting of the crop are presented in this report.

PLAN OF THE EXPERIMENT

Five varieties were selected for this study and were continued until the last year (1940) when one was dropped and only four were tested. These varieties, under average conditions, covered a range in staple length from a short $\frac{15}{16}$ inch to a full $1\frac{1}{16}$ inch. Because of the problems of isolation and acreage necessary for increase, it was not possible to include varieties representing all of the most widely grown types. The varieties were chosen, therefore, on the basis of origin. The group included two varieties of recent hybrid origin. A third variety had been developed from a cross made 15 years previously and had been thrown back repeatedly to a single plant until the type was reasonably uniform. The other two varieties had not had any known hybridization for more than 25 years.

Since the beginning of this work, three of these varieties have been discontinued by the originators. The other two are still being maintained and are being used by farmers to some extent. It is not believed that these results would receive added value by disclosing the identity of the varieties used. They will, therefore, be referred to by number and are briefly described in Table 1. The word "selection" as used in this tabulation indicates that there had been no known hybridization for more than 10 years.

In this report the terms "breeder" generation and "farmer" generation are used. The first, second, and third breeder generations imply that seed of the second has had one more year of attention from the breeder than the third and, likewise, that seed of the first has had one more year of attention from the breeder than the

[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Published with the approval of the Director. Received for publication March 16, 1942.

[2]Agronomist and Plant Breeder.

second. In other words, "breeder" seed would be maintained by whatever eliminations the breeder might feel justified in making in his improvement block each year. On the other hand, the first, second, and third "farmer" generations would imply that the stock of seed originally obtained by the farmer was increased year after year, taking only the precautions necessary to prevent mixing with other varieties.

TABLE 1.—*Certain characteristics of varieties used.*

Variety No.	Method of origin	Lint percentage	Staple, inches	Bolls per lb. of lint
26	Recent hybrid	36–38	1 1/32–1 1/16	195–200
35	Selection	33–35	31/32–1	190–195
43	Selection	34–36	1–1 1/32	230–235
48	Recent hybrid	35–37	31/32–1	200–205
57	Selection	32–35	15/16–31/32	230–235

In order to compare several generations of a variety it was first necessary to produce them. The extensive area covered by the Experiment Station farm fitted it almost ideally to the setting aside of an isolated field for the increase of each variety. In each of these increase fields the most uniform block was set aside for a plant-to-row test of the variety assigned to it. This block was filled with progeny rows planted with selections made in the progeny block of the same variety the previous season. A block, usually nearby, was planted with material field selected plant by plant the previous season. The remainder of the field was divided into enough increase blocks to provide one for each generation to be increased. These blocks were usually 30 to 50 rows in width.

When the cotton was ready for harvest, selections were taken from the progeny rows. After being culled in the laboratory, these were used to plant the progeny block the following year. After the selections referred to were removed, the progenies were then harvested separately and compared as to yield, lint percentage, staple length, and any differences noted in the field. About 20 to 30% of the best progenies were massed for increase the following year. These steps comprise the essential features of variety maintenance by the "massed progeny" method as it was practiced in this case.

From the massed selection block plants were selected individually and massed for increase the following year. After the selections referred to were removed a sample for test and further increase the following year was taken as indicated below.

At harvest there was removed from the center of each increase block a seed cotton sample great enough to provide ample seed for a test and another increase block the following year. This sample would usually require the cotton from four to eight of the middle rows of the block. These samples were bagged, properly tagged, and stored. The remaining rows of each block were picked and treated as mixed cotton.

The increase procedure outlined prevented cross pollination between varieties. There was, of course, a small amount of cross pollination between adjacent increase blocks of the same variety. The effects of this were minimized by drawing the sample for further use from the center of the block. In the worst cases, where the proportion of bare seed had increased greatly, the increase blocks were given additional isolation. In any case an increase block of any particular generation would adjoin a block or blocks no more than one generation removed.

It was assumed that if degeneration does not occur the small amount of cross pollination between adjacent increase blocks would produce no effect. If, on the other hand, degeneration does occur, it should be in spite of such cross pollination as well as because of it. That is, where first and second generation increase blocks adjoin, it would appear possible for reciprocal cross pollination to be partly compensating in its effects.

During the winter months following the completion of harvesting, the bagged samples were ginned on a 20-saw gin with ample precautions to prevent mechanical mixing of the several generations. A portion of the seed of each generation was treated with ceresan and set aside for yield and other trials. The remainder was left untreated and used for further increase and as a reserve.

After the increase work just described had progressed sufficiently, tests were inaugurated for comparing the several generations. These tests were randomized with six replications of single-row plots. In harvesting the tests only two samples were saved from each test to determine lint percentage. Two 100-boll samples were likewise saved from each test for studies on boll size and staple length. Only the seed cotton yields were subjected to analysis of variance.

RESULTS AND DISCUSSION

Two types of comparative field trials were made. The first type included several breeder generations of each variety. These generations, as previously indicated, differed not only by the number of years of increase from the improvement block, but also by any changes which may have been produced in the improvement block. For example, if a variety is maintained by the massed progeny method, the material massed for increase each year is subjected to whatever eliminations the breeder's studies may appear to justify. It follows, therefore, that if the variety is susceptible of improvement and the breeder's observations are accurate the variety may show improvement from year to year. A distinction must be drawn between changes by improvement of newer generations and changes by degeneration of older generations.

Tables 2 and 3 give the essential data from the tests comparing breeder generations in 1938 and 1939. For several years prior to 1938 similar data were obtained. These earlier results are not reported here. They show essentially the same trends as do the 1938 results and there were, of course, fewer generations to be compared.

In the tables the "average rating" for the several generations is given. This rating was determined by expressing the results of each generation of each variety in percentage of the first generation. These percentages for each generation of all varieties were then averaged to obtain the average rating.

These average rating values are not presented as being without fault. For example, after the sixth generation in Table 2 and after the seventh generation in Table 3, not all varieties are represented. In addition, variety 26 did not show the downtrend in lint percentage which was shown by some other varieties, although there was some indication in Table 3 that this was about to begin. If this variety were eliminated from the averages, the lint percentage decreases would have been greater in the mid-generations.

There was a considerable, although irregular, increase in the proportion of bare seed (seed without fuzz hairs) in the generations as the number of years from the improvement block increased. A part of the irregularity observed can be attributed to the difficulty of mixing thoroughly a few pounds of cotton seed. Even counting eight lots of 100 each taken at random from eight points in the sample sometimes did not reveal the presence of bare seed, although one might occasionally be observed during the mixing. Soil moisture variations in the increase blocks at planting time probably contributed most to bare seed irregularities. These increase blocks were of considerable size and usually varied materially in soil moisture from block to block. How soil moisture variations could cause bare seed to increase more rapidly than fuzzy seed will be explained presently.

Theoretically, if a cotton variety is released with one homozygous bare seed to each 10,000 fuzzy seed, the ratio should not change year after year unless some environmental or other factor affects the two classes differently. Practically, there are factors which do produce differences by the way in which they affect the survival of the seed. A combination of low soil moisture and medium to high temperatures often prevails just after planting. When this occurs, bare seed will often germinate and may make one to two weeks growth before a rain provides enough moisture to cause the fuzzy seed to germinate. Naturally, the best-looking plants will be left when the seedlings are thinned to a normal stand. Such plants, having become established much earlier than others, will produce more flowers and thus provide a disproportionate share of pollen for nearby plants in addition to producing an abundant seed crop themselves.

The genes causing the bare seedcoat either were present in these seed stocks at the beginning of the work or arose later through mutation. Since there is not definite proof that such mutations occur frequently, it appears advisable to present these results with the assumption that the bare seed genes were present in these seedstocks at the beginning of the study, although not to the extent that they could be readily detected. The possibility that mutation may have played a part should not be completely ignored, however, since Afzal and Singh (1),[3] Beasley (2), Stroman (4), Yu (6), and others have shown that mutations in cotton are not extremely rare.

There appeared to be, with some exceptions, a decrease in lint percentage as the years from the breeding block increased. As previously pointed out, a variety susceptible of being changed by selection could have been so changed by the procedure followed in the breeding block. It may well be, therefore, that the apparent decrease in lint percentage in the older generations was due in part to an increase in the newer generations as a result of selection. Since, however, there was a fairly consistent relation between a high proportion of bare seed and low lint percentage, as shown in Tables 2 and 3 and in Fig. 1, and since the type of bare seed present has a very low lint percentage in the homozygous condition, it seems safe to conclude that much of the decrease in lint percentage was due to the increase in the proportion of bare seed.

[3]Figures in parenthesis refer to "Literature Cited", p. 796.

TABLE 2.—*Results from breeder generation tests, 1938.*

Variety No.	Years or generations from breeding block									
	1	2	3	4	5	6	7	8	9	10
					Lint Percentage					
26	37.7	37.7	37.8	38.2	37.3	37.4	—	—	—	—
35	34.8	34.4	34.8	34.2	33.1	34.2	33.3	—	—	—
43	35.9	36.5	35.9	35.0	34.5	35.1	35.1	—	—	—
48	35.8	35.3	35.7	39.1	35.5	35.6	34.7	35.3	28.8	33.2
57	34.2	35.1	33.7	34.4	33.6	33.5	33.6	33.5	33.0	—
Av. rating	100.0	100.35	99.71	101.38	97.51	98.52	97.15	98.27	88.47	92.74
					Bare Seed per 800					
26	0.0	0.0	0.0	0.0	0.0	0.0	—	—	—	—
35	0.0	2.0	0.0	0.0	0.0	0.0	24.0	—	—	—
43	1.0	0.0	0.0	39.0	126.0	26.0	5.0	—	—	—
48	0.0	0.0	1.0	4.0	10.0	0.0	32.0	6.0	220.[illegible]	101.0
57	0.0	0.0	4.0	0.0	0.0	0.0	9.0	8.0	[illegible].0	—
Av. percentage	0.05	0.10	0.25	2.15	6.80	1.30	4.37	1.75	27.50	25.25

					Pounds of Lint per Acre					
26	389.1	386.8	399.9	361.4	382.0	376.2	—	—	—	—
35	436.0	447.9	453.8	444.3	432.3	420.7	418.2	—	—	—
43	490.4	504.4	494.0	475.3	472.0	480.9	469.6	—	—	—
48	384.5	377.7	400.6	380.8	399.7	383.8	338.0	342.4	318.6	351.9
57	280.1	276.2	292.9	282.4	269.8	265.7	289.6	275.0	256.4	—
Av. rating	100.00	100.37	103.27	98.31	98.76	97.18	95.74	93.61	87.20	91.52
					Pounds of Seed Cotton per Acre					
26	1,032.0	1,026.0	1,058.0	946.0	1,024.0	1,006.0	—	—	—	—
35	1,253.0	1,302.0	1,304.0	1,299.0	1,306.0	1,230.0	1,256.0	—	—	—
43	1,366.0	1,382.0	1,376.0	1,358.0	1,368.0	1,370.0	1,338.0	—	—	—
48	1,074.0	1,070.0	1,122.0	974.0	1,126.0	1,078.0	974.0	970.0	1,122.0	1,060.0
57	819.0	787.0	869.0	821.0	803.0	793.0	862.0	821.0	777.0	—
Av. rating	100.00	100.04	103.58	97.14	101.30	98.62	98.53	95.28	99.67	98.70
					Number of Bolls to 1 Pound of Lint					
Av. rating	100.00	99.71	100.12	98.49	100.70	99.32	103.18	104.41	117.06	111.59
					Staple Length					
Av. rating	100.00	100.48	100.56	100.43	99.45	98.98	99.16	98.42	99.65	95.83

TABLE 3.—*Results from breeder generation tests, 1939.*

Variety No.	Years or generations from breeding block										
	1	2	3	4	5	6	7	8	9	10	11
					Lint Percentage						
26	36.9	36.7	36.9	37.3	37.6	35.9	36.4	—	—	—	—
35	34.4	34.3	34.1	34.9	34.0	33.3	34.0	33.7	—	—	—
43	35.4	36.4	35.7	35.0	34.0	30.8	34.3	36.0	—	—	—
48	36.0	35.4	35.3	35.9	35.0	34.9	33.9	35.0	34.3	30.7	31.5
57	32.7	32.8	34.0	33.6	33.0	32.5	33.3	32.4	32.4	32.2	—
Av. rating	100.00	100.13	100.40	100.57	98.98	95.48	98.07	98.99	97.18	91.87	87.50
					Bare Seed per 800						
26	0.0	0.0	0.0	0.0	4.0	14.0	1.0	—	—	—	—
35	3.0	1.0	0.0	0.0	1.0	0.0	0.0	231.0	—	—	—
43	0.0	0.0	6.0	24.0	215.0	584.0	164.0	7.0	—	—	—
48	0.0	0.0	0.0	0.0	0.0	8.0	49.0	133.0	121.0	487.0	393.0
57	0.0	0.0	0.0	100.0	1.0	0.0	3.0	113.0	78.0	120.0	—
Av. percentage	0.07	0.02	0.15	3.10	5.52	18.94	5.42	15.12	12.44	37.94	49.12

Pounds of Lint per Acre											
26	319.0	329.1	298.7	316.5	322.5	307.9	301.3	—	—	—	—
35	261.1	265.0	292.4	256.1	284.5	284.8	279.9	278.2	—	—	—
43	373.1	322.5	332.7	250.6	322.3	298.1	302.5	311.8	—	—	—
48	193.7	174.9	201.9	168.0	220.4	209.4	206.8	225.4	219.5	198.3	189.6
57	334.2	301.1	310.8	296.4	285.9	297.7	307.7	291.6	304.6	294.3	—
Av. rating	100.00	94.30	98.41	87.98	99.11	96.54	96.31	98.43	102.23	95.21	97.88
Pounds of Seed Cotton per Acre											
26	864.5	896.6	809.4	848.4	857.6	857.6	827.8	—	—	—	—
35	759.0	772.7	957.6	733.8	836.9	855.3	823.2	825.5	—	—	—
43	1,054.0	886.0	932.0	716.0	948.0	968.0	882.0	866.0	—	—	—
48	538.0	494.0	572.0	468.0	628.0	600.0	610.0	644.0	640.0	646.0	602.0
57	1,022.0	918.0	914.0	882.0	864.0	916.0	924.0	900.0	940.0	914.0	—
Av. rating	100.00	94.24	98.16	87.21	100.13	100.98	98.33	99.67	105.46	104.75	111.89
Number of Bolls to 1 Pound of Lint											
Av. rating	100.00	100.73	99.96	100.05	99.64	104.55	101.84	103.50	103.36	110.66	116.25
Staple Length											
Av. rating	100.00	98.73	99.35	99.14	99.46	99.77	98.91	98.11	97.96	96.80	94.42

Since lint percentage may be modified by seed size, seed index data were collected. There seemed to be no material change in seed index from year to year in either the breeder or farmer generations. Seed index, therefore, could have had little effect on changes in lint percentage. The data are omitted to conserve space.

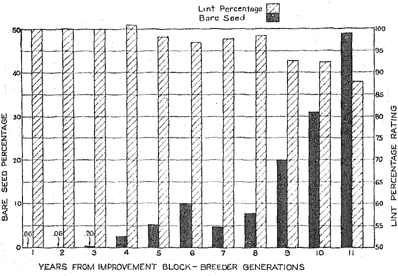


FIG. 1.—Bare seed and lint percentage, breeder generations.

The irregularities in the downtrend of lint per acre result from the fact that the seed cotton yields in the 1938 tests show no downtrend and in the 1939 tests they show an actual uptrend. This tendency for the seed cotton yields to increase in the older generations can be attributed, in part, to two causes. In the first place, cotton breeders have found it difficult to increase lint percentage without reducing seed cotton yields. Their low percentage strains usually produce more seed cotton than their high percentage strains. This problem has been only partly overcome in a few cases. In the second place, a bare seed, heterozygous for the bare characteristic, might germinate one to two weeks ahead of seed with fuzz. Since the lint percentage would be only a little below normal (5), the seed cotton yield could actually be greater than that of the seed with fuzz which germinated later.

The seed cotton yields were subjected to analysis of variance. In a few cases the F values were less than required for significance at the 5% point. In some cases the F values were greater than required for significance at the 1% point. The majority of the values fell in between. Pounds of seed cotton per acre required for significance varied from 70 to 110. Significant differences in seed cotton yields from the several breeder generations here tested were not definitely established.

The uptrend in the number of bolls to 1 pound of lint may be attributed largely to the downtrend in lint percentage.

The decrease in staple length was not great and may have been due to improvement of the newer generations by the removal of much short material in the breeding block.

TESTS COMPARING FARMER GENERATIONS

The results of these tests are greatly condensed in Table 4. Thus, instead of reporting the data for each generation of each group of each variety, averages are used where possible. This is done to simplify the study and conserve space, although it prevents study of variations within groups and within varieties.

In these tests which compare farmer generations the results were not affected by any breeding procedure employed in the maintenance block. For example, in the first line of data in Table 4 the lint percentages of the first, second, and third generation are compared. The first generation was produced by increasing seed just from the breeding block. A part of the first generation seed was used to produce the second and a part of the second was used to produce the third. While each generation was being produced, reserve seed of the previous generations, if any, was held in storage. As a consequence, there was no difference between the seed of the several generations of any one group except what was brought about by environmental differences in the increase and test blocks.

The results from the farmer generation tests (Table 4 and Fig. 2) show the same general trends as are shown by the breeder generation tests (Tables 2 and 3), although to a less extent. Lint percentage, with few exceptions, decreased from year to year. This decrease appeared to be greatest in 1939 when the proportion of bare seed was greatest. The relation between the decrease in lint percentage and the increase in bare seed appears to be close. The percentage of bare seed was greater in 1939 than in 1940. This could have been caused largely by germinating conditions favorable to bare seed in the former year and unfavorable in the latter.

The irregularities in lint cotton yields must be attributed to the behavior of the seed cotton yields.

The trend in seed cotton yields was irregular. The 1938 results showed downtrends with differences which were barely significant. This trend was less in the 1939 tests and was reversed in those of 1940. There are three factors which should be considered in connection with these irregularities. First, is the fact that in these tests the seed of any two generations in one group differed in age. That is, seed of generation one was in storage while seed of generation two was being produced. Likewise, seed of both were in storage while the third was being produced. Thus, in the 1940 tests, seed of generation one was four years older than seed of generation five. The stands obtained in the tests appeared to be adequate in all cases. These age differences may not have affected yields materially, but it hardly seems wise to ignore them in an evaluation of the results.

The second factor to be considered here is the fact that rainfall in June and July of 1940 was 14.73 inches above the long-time average and it was also excessive in 1939. It hardly seems safe to assume that

TABLE 4.—*Tests comparing "farmer" generations.*

Year	Varieties averaged	Generations grouped	Generation 1	2	3	4	5	6
			Lint Percentage					
1938	5	10	35.0	34.9	35.0	—	—	—
1938	5	9	—	35.2	34.8	34.6	—	—
1938	5	8	—	—	34.7	34.5	34.2	—
1939	5	10	36.2	36.1	35.9	35.5	—	—
1939	5	9	—	36.0	35.8	35.7	35.3	—
1939	5	6	—	—	35.1	34.7	34.6	34.0
1940	4	8	36.1	35.9	35.7	35.7	35.5	—
1940	4	7	—	35.9	35.8	35.6	35.5	35.2
			Bare Seed Percentage					
1939	5	10	0.01	0.01	0.55	1.67	—	—
1939	5	9	—	0.45	0.46	1.50	5.92	—
1939	5	6	—	—	1.95	2.97	5.25	14.22
1940	4	8	0.01	0.55	1.87	1.52	1.51	—
1940	4	7	—	0.01	0.36	0.76	4.20	4.99

				Pounds of Lint per Acre				
1938	5	10	399.5	378.9	367.9	—	—	—
1938	5	9	—	377.9	346.2	365.5	—	—
1938	5	8	—	—	396.6	358.2	381.7	—
1939	5	10	427.7	413.6	429.1	402.7	—	—
1939	5	9	—	439.3	419.9	430.3	413.8	—
1939	5	6	—	—	399.4	399.6	399.3	390.1
1940	4	8	339.6	335.7	341.5	345.9	343.7	—
1940	4	7	—	360.3	336.9	347.3	357.3	356.3
				Pounds of Seed Cotton per Acre				
1938	5	10	1,139.6	1,082.5	1,047.0	—	—	—
1938	5	9	—	964.3	889.3	947.8	—	—
1938	5	8	—	—	912.6	826.4	862.2	—
1939	5	10	1,181.6	1,148.2	1,194.1	1,134.0	—	—
1939	5	9	—	1,219.3	1,172.6	1,204.4	1,172.5	—
1939	5	6	—	—	1,139.0	1,150.2	1,153.5	1,148.3
1940	4	8	944.5	938.9	961.3	973.2	971.7	—
1940	4	7	—	1,006.9	945.0	981.4	1,010.2	1,016.1
				Bolls Required to Make 1 Pound of Lint (av. rating)				
1938–40	5	10	100.0	100.3	100.8	102.1	103.3	—
1938–40	5	9	—	100.0	101.3	102.4	102.3	102.3

the several generations of even one variety will respond with the same relative results under such environmental extremes. A variety can easily be a pure line for a simple character like lint color, but its hereditary response to differences in environment should be rather complex. The several generation groups and, to some extent, the individual generations of any variety should be regarded as mixtures of lines so far as reponse to climatic variations is concerned.

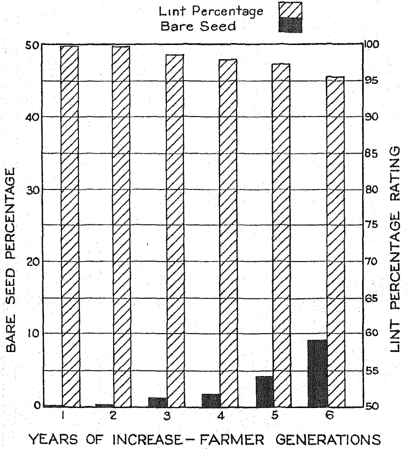


FIG. 2.—Bare seed and lint percentage, farmer generations.

The third factor to be remembered in connection with the foregoing is that, while breeders are usually able to produce varieties with high lint percentage, it is usually done at the expense of seed cotton yield. It hardly seems unreasonable, therefore, to assume that changes which cause a decrease in lint percentage from year to year might, to some extent, also cause an increase in yield of seed cotton. It would even be possible, as appears to have been the case in 1939 especially,

for seed heterozygous for bare seed coat to germinate far ahead of fuzz-covered seed and thus be able to outproduce the latter in both seed cotton and lint.

The number of bolls required to make a pound of lint showed an uptrend in the tests of each of the three years. This is almost a direct reflection of the downtrend in lint percentage. Average ratings by generation groups are given.

There was no apparent trend in staple length and for that reason the data are omitted. Moore (3) found no change in staple length in somewhat similar tests covering three years.

It has been assumed in this report that the decreases in lint percentage were due largely to increases in the proportion of bare seed. It should be possible for other modifiers of lint percentage to cause such decreases. For example, if two varieties differing widely in lint percentage produce about equal yields of lint cotton, it follows that the one with the low lint percentage would be the greater seed producer, provided the seed indices were the same. Now if seed of these varieties were mixed in equal proportions and planted and the seed from this mixture used for further planting, it should be only a few years until the low lint percentage genes would largely predominate since they accompany greater seed production. Thus, in a theoretical setup of this kind high lint percentage genes would be gradually eliminated. The same thing could happen within a variety if the factors affecting lint percentage are heterozygous and vary widely.

It may be inferred from the foregoing that if a variety with a low lint percentage is mixed slightly in the field or at the gin with one having a high percentage there might be little change in lint percentage and perhaps in yield. On the other hand, if a high lint percentage variety were so mixed with a low one the results would very likely be a decrease in lint percentage from year to year, and possibly an increase in seed cotton yield. This, of course, would be greatly affected by the inherent productive ability of the varieties involved.

SUMMARY

Five standard varieties of cotton were tested to determine what changes occur within the variety when mixing with other varieties is prevented.

The proportion of bare seed increased as the variety was reproduced year after year. This increase was slow at first and progressed more rapidly in later years. In a few cases it rose above 50%.

The increase of bare seed was more rapid in some varieties than in others. This was probably due to differences in the proportion of bare seed contained in the stocks at the beginning and differences in soil moisture in the reproduction areas.

A decrease in lint percentage was observed as reproduction progressed and this was attributed largely to the increase in bare seed with their accompanying low lint percentage.

Other changes were less marked. The increasing number of bolls required to give a pound of lint cotton was probably a direct result of

the decrease in lint percentage. Changes in seed cotton yields and staple length were too small and variable to be properly evaluated.

No evidence was obtained indicating that a variety of recent hybrid origin will necessarily change more rapidly than others.

These results support the existing belief that the chief cause of cotton varietal deterioration results from the mixing of varieties whether in fields, places of storage, or at gins.

LITERATURE CITED

1. AFZAL, M., and SINGH, S. Genetics of a petaloid mutant in cotton. Indian Jour. Agr. Sci., 9:787–790. 1939.
2. BEASLEY, J. O. Production of polyploids in gossypium. Jour. Her., 31:39–48. 1940.
3. MOORE, J. H. The influence of any internal change in a standard variety of cotton upon fiber length. Jour. Amer. Soc. Agron., 33:679–683. 1941.
4. STROMAN, G. N. A heritable female-sterile plant in cotton. Jour. Her., 32:168–169. 1941.
5. WARE, J. O. Genetic relations of sparse lint, naked seeds, and some other characters in upland cotton. Ark. Agr. Exp. Sta. Bul. 406. 1941.
6. YU, C. P. The genetical behavior of three virescent mutants in Asiatic cotton. Jour. Amer. Soc. Agron., 33:756–758. 1941.

GERMINATION AND EMERGENCE OF SOME NATIVE GRASSES IN RELATION TO LITTER COVER AND SOIL MOISTURE[1]

George E. Glendening[2]

UNDER the warm, arid conditions which prevail on the grazing ranges of southern Arizona, the establishment of seedlings of perennial forage grasses appears to be controlled mainly by soil moisture (3).[3] Early artificial reseeding trials in southern Arizona were, without exception, reported to be largely unsuccessful, and in every case (4, 7, 8) unfavorable moisture conditions were cited as the primary cause of failure. Subsequent tests have shown that in this region the chances for germination of perennial grass seeds on bare exposed soils are extremely poor; but where the seed was covered with litter in the form of straw or hay, germination and emergence was markedly increased.[4]

During the summer of 1938, experiments were conducted on the Santa Rita Experimental Range[5] to determine the effect of various kinds of litter cover upon soil moisture and germination and emergence of seedlings of 10 native grasses.

THE STUDY AREA

The study area lies at an elevation of 3,000 feet on one of the many ridges that slope gently to the northwest from the Santa Rita Mountains. The vegetation, although once comprised mainly of perennial grasses, now consists largely of woody plants, such as burroweed (*Aplopappus fruticosus*), false-mesquite (*Calliandra eriophylla*), mesquite (*Prosopis velutina*), and cacti (*Opuntia* spp.). Scattered remnants of perennial forage grasses may still be found on the most favorable sites.

The soil on the study area is of alluvial origin and is classified as Continental gravelly loam (9). Much of the friable topsoil has been washed away and in many places a layer of small pebbles or "erosion pavement" covers the soil surface. This, together with the sparsity of vegetation, has resulted in conditions that are very unfavorable to moisture penetration and retention.

The climate of the area is typical of southwestern semidesert regions, and has been reported in detail by McGinnies and Arnold (6). Total yearly rainfall at the specific site of the study, based on 8 years' records, is approximately 12.5 inches. Soil and air temperatures are characteristically high during the summer season, and together with low relative humidities result in excessively high evaporation and rapid drying of the exposed surface soils.

---

[1]Contribution from the Southwestern Forest and Range Experiment Station, Tucson, Ariz. Received for publication March 23, 1942.

[2]Associate Forest Ecologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 803.

[4]Mimeographed Research Notes Nos. 7 and 19, Southwestern Forest and Range Experiment Station, Tucson, Ariz.

[5]A branch station of the Southwestern Forest and Range Experiment Station located 35 miles southeast of Tucson, Ariz.

EXPERIMENTAL PROCEDURE

In July 1938, two small plots were selected and carefully cleared of their sparse vegetative cover. The disturbed soil was then allowed to be settled by a good rain prior to further treatment. One plot 16 by 16 feet in size was divided into three equal parts, of which one part was covered lightly with barley straw, a second part was covered with open-mesh cotton gauze fabric,[6] and the remaining part was left bare. From this plot samples of soil for moisture determinations were obtained at twice weekly intervals from the surface-inch, 6-inch, and 12-inch levels under each of the three treatments. Moisture determinations were made by the standard method of desiccation at 105° C for 24 hours. At the end of the study, samples of soil were tested by the centrifuge method (1) for determination of "moisture equivalent," and from this the "wilting coefficient of the soil" was determined indirectly (2) to be 3.58%.

PLANTING TECHNIC

On the second plot, which was 28 by 94 feet in size and located near the soil-moisture plot, seeds of 10 native perennial grasses were planted on July 11 under the following treatments:

1. No treatment after the seed was applied on the bare ground.
2. Seed raked into surface soil to simulate light cultivation.
3. Seed covered with barley straw.
4. Seed covered with chopped stems of the locally abundant burroweed.
5. Seed covered with open-mesh gauze fabric.
6. Seed raked into surface soil and covered with barley straw.
7. Seed raked into surface soil and covered with chopped stems of burroweed.
8. Seed raked into surface soil and covered with open-mesh gauze fabric.

The 10 grasses were as follows:

Scientific Name	Common Name
Bouteloua eriopoda	Black grama
Bouteloua Rothrockii	Rothrock grama
Bouteloua chondrosioides	Sprucetop grama
Bouteloua filiformis	Slender grama
Bouteloua hirsuta	Hairy grama
Aristida divaricata	Poverty three-awn
Aristida glabrata	Smooth three-awn
Trichachne californica	Arizona cottongrass
Heteropogon contortus	Tanglehead
Hilaria belangeri	Curly-mesquite

Each planting treatment was replicated three times for each of the 10 species according to a randomized block design. Individual treatment plots were 1 foot square and separated on all sides by isolation strips 2 feet wide. The seeded plots were examined weekly, and the data given in this paper regarding germination and emergence of seedlings are from counts made August 18, 38 days after the planting date.

RESULTS

Nine days after planting, the soil was well moistened by a rain of

[6]This fabric was furnished by the Agricultural Adjustment Administration. It is 40 inches wide, is made of twisted cotton string, 5 strands to the inch each way, and has 17 warp threads and 5 filling threads per inch.

1.03 inches. This resulted in germination of some seeds, but the bulk of the germination occurred during the early part of August when moisture conditions were favorable during a period of about 10 days. In general, conditions for plant development between July 11, the planting date, and August 18, the date of final observation, were about typical of those which prevail on this and similar areas in southern Arizona during the summer growing season. Data for air temperature, evaporation, rainfall, and soil moisture are given in Table 1.

In Table 1 it may be noted that maximum daily air temperature varied from 82° to 105° F and averaged 93° for the 41-day period. Records obtained on differential thermographs, with the elements set to obtain the differences between surface-soil temperature of the bare ground and that under the straw litter and gauze fabric, were unsatisfactory and are not shown. The few records that were obtained indicated a maximum difference between temperature of the bare soil and that under the straw and gauze fabric in excess of 50° F. Records of surface-soil temperatures taken at Desert Grassland Station for a comparable 41-day period during July and August of 1940 show a maximum surface-soil temperature of 162° F with a mean of 135° F. At that station the mean daily difference between maximum soil and air temperatures was 41° F for the period July 10 to August 19, 1940.

Total rainfall during the study period was 4.93 inches. This was accompanied by a mean daily evaporation rate of 0.323 inch, which amounts to 13.23 inches, or more than two and a half times the total rainfall during the 41-day study period.

The soil-moisture data in Table 1 clearly show that the moisture content of the surface soil was consistently higher under the barley straw than with the bare soil, and that moisture content of the gauze-covered soil was somewhat above that of the bare soil. Average moisture content of the surface soil during the study period was 2.7, 5.9, and 3.3%, respectively, for the bare soil, soil under straw, and that under gauze fabric. Average soil moisture at the 6-inch level was 6.1, 7.6, and 6.4%, in the same order, while at the 12-inch depth it was 6.6, 7.2, and 6.9%.

Table 2 lists by species the average number of seedlings per square foot that germinated and emerged under the various planting treatments. Inasmuch as seeds of unknown viability and purity were planted, comparisons of seedling numbers between the different species are not allowable. However, equal amounts of seed-bearing material were planted under all treatments for a given species so that comparisons between treatments are valid. It may be noted that all the various soil treatments markedly increased germination and emergence over that which occurred on the bare, untreated soil. Based on the means for all species, these increases varied from approximately 400% with cultivation alone to more than 2,000% under the open-mesh gauze fabric, while within some of the individual species an even greater response to the various treatments may be noted. An analysis of variance of the original seed plot data from which Table 2 was derived is given in Table 3.

TABLE 1.—*Climatological data for the 41-day study period.*

Date	Air temperature, °F	Evaporation,* inches	Rainfall, inches	Soil moisture in surface inch: Bare, %	Covered with straw, %	Covered with gauze fabric, %
July 10	99	0.452	—	—	—	—
11	89	0.194	0.01	—	—	—
12	94	—	—	—	—	—
13	93	0.259	—	—	—	—
14	99	0.439	—	—	—	—
15	97	—	—	—	—	—
16	94	0.299	—	—	—	—
17	93	0.242	0.15	—	—	—
18	97	0.244	—	—	—	—
19	97	0.462	—	—	—	—
20	97	0.520	1.03	—	—	—
21	91	0.388	—	6.8	9.7	8.6
22	89	0.420	0.02	—	—	—
23	87	0.293	0.04	—	—	—
24	83	0.202	—	3.3	5.8	3.3
25	84	0.218	—	—	—	—
26	92	0.199	—	0.7	2.8	0.7
27	97	0.346	—	—	—	—
28	95	0.325	—	0.4	2.0	0.4
29	97	0.374	—	—	—	—
30	99	0.411	—	—	—	—
31	105	0.540	—	—	—	—
Aug. 1	105	0.494	—	0.2	0.6	0.4
2	101	0.567	—	—	—	—
3	95	0.252	0.17	—	—	—
4	89	0.255	0.51	0.8	2.1	1.7
5	90	0.282	—	—	—	—
6	90	0.328	2.02	—	—	—
7	85	0.137	—	8.0	12.8	8.5
8	91	0.370	—	—	—	—
9	94	0.407	—	4.1	5.5	4.1
10	94	0.306	—	—	—	—
11	98	0.502	—	0.7	6.9	1.3
12	93	—	0.98	—	—	—
13	82	0.162	—	—	—	—
14	89	0.393	—	6.3	8.4	8.2
15	89	0.382	—	—	—	—
16	89	0.368	—	1.4	7.7	1.4
17	91	0.423	—	—	—	—
18	92	0.449	—	—	—	—
19	95	0.325	—	T	6.6	1.0
Total...	—	13.229	4.93	—	—	—
Mean...	93	0.323	—	2.72	5.91	3.30

*From shallow blackened tank at Desert Grassland Station, 6½ miles east of the study area, courtesy Range Ecology Department, University of Arizona.

This analysis shows that differences of means due to treatment, blocks, and species are significant at the 1% level. The indicated difference between blocks is believed due to the fact that one of the blocks, being slightly lower in elevation than the other two, received

TABLE 2.—*Germination and emergence of perennial grass seedlings under different soil treatments.*

Treatment	Number of seedlings per square foot*										
	Black grama	Roth-rock grama	Spruce top grama	Slender grama	Hairy grama	Poverty three-awn	Smooth three-awn	Arizona cotton-grass	Tangle-head	Curly mes-quite	Mean
None	6	3	2	1	18	8	14	1	15	0	7
Raked lightly	19	5	7	16	110	62	50	8	45	0	32
Covered with straw	26	7	37	53	203	203	38	32	66	2	67
Covered with burroweed†	46	10	14	17	223	143	36	196	54	4	74
Covered with open-mesh gauze	86	43	47	196	400	283	132	313	88	5	159
Raked lightly and covered with straw	23	5	16	144	240	183	49	60	104	6	83
Raked lightly and covered with burroweed	21	14	22	137	250	167	55	105	98	3	87
Raked lightly and covered with open-mesh gauze	84	27	62	117	517	240	115	203	62	2	143

*Mean from three replicates.
†Aerial portion of burroweeds broken and chopped to form litter.

some runoff water from the adjacent area and produced a greater number of seedlings under all treatments. As previously stated, the apparent differences between species are not valid because of the variation in viability and purity of the seed of the various species planted.

TABLE 3.—*Test of significance of differences.*

Source of variance	D.F.	Sum of squares	Variance	F.	Sig.
Total	239	3,437,970.600	—	—	—
Between blocks	2	81,879.375	40,939.688	7.561	**
Between treatments	7	543,409.267	77,629.895	14.337	**
Between species:	9	1,223,284.683	135,920.520	25.102	**
Blocks × treatments	14	73,865.558	5,276.111	1.026	—
Blocks × species	18	235,484.792	13,082.488	2.416	**
Treatment × species	63	597,785.983	9,488.666	1.752	**
Error	126	682,260.942	5,414.769	—	—

DISCUSSION

The greater moisture content of the surface soil under the straw litter and the gauze fabric may have been partly due to more effective moisture intake since excessive runoff is common on bare soils during high-intensity summer rains. However, the reduced evaporation rate that would result from the greatly lowered temperatures under the straw and gauze must undoubtedly have been a major contributing factor. Based on the soil-moisture data best results should have been expected under the straw litter. The precise reason for the slightly greater number of seedlings under the gauze fabric than under the barley straw was not definitely determined, but one possible reason may have been the more effective protection of the seeds from depredation by birds and rodents that was afforded by the cotton mesh fabric.

The marked increase in germination obtained through the use of chopped burroweed stems should be of particular significance inasmuch as it indicates the possibility of using the natural litter from this and similar other undesirable shrubs as an aid to natural or artificial revegetation of depleted grassland ranges.

With regard to cultivation, it is obvious that this treatment, through covering the seed and aiding moisture penetration, is a distinct aid on soils with a bare, deteriorated surface. However, the results here obtained appear to indicate that cultivation is not essential where the soil is covered with some form of litter, which is in accord with the well-known fact that, under natural conditions, germination of seed of these grasses normally takes place at or very near the soil surface.

In this region, summer rainfall occurs characteristically in the form of intermittent showers separated by periods of extremely dry weather during which the upper soil layers may become completely desiccated, despite the fact that available moisture may be present only a short distance below the soil surface. Consequently, seeds which

lie on or near the soil surface are subjected to alternate periods of wetting and drying. While this process of recurrent swelling and shrinking of the seedcoats and partial germination may not completely devitalize some seeds (5), it has been observed in this region that seeds which have been so treated often fail to sprout when conditions favorable for germination are subsequently encountered.

Not only is germination dependent upon an available supply of surface moisture, but later essential developmental processes, including the initiation of adventitious roots and tillering, are also markedly curtailed or even prohibited by a deficiency in surface-soil moisture (3). Consequently, any cultural treatment, such as covering the soil with artificial litter, which tends to increase the moisture content of the surface soil and to prolong the intervals during which surface moisture is available may be expected to be an aid to germination and the ultimate establishment of perennial grass seedlings.

Under conditions of proper grazing use in the semidesert grassland type some litter accumulates on the soil surface and serves partially to insulate young seedlings and the soil surface from the drying effect of the atmosphere; but where grazing from livestock has been intense over prolonged periods, this protective litter cover is often almost entirely lacking. On areas where the grass cover has become seriously depleted, stands of seemingly worthless plants, such as burroweed, annual grasses, and annual weeds, may, in the final analysis, be of distinct value in that they provide some litter under which the natural processes of grass regeneration can take place when other factors become favorable.

SUMMARY

1. During the summer of 1938 seeds of 10 native perennial grasses were planted in replicated plots under eight different treatments, including cultivation and covering of the surface soil with various kinds of litter on a depleted semidesert grassland range south of Tucson, Ariz. At the same time provision was made on an adjacent plot to obtain moisture samples at surface-inch, 6-inch, and 12-inch depths of bare soil, soil covered with straw litter, and soil covered with open-mesh gauze fabric.
2. Results showed that moisture content at all levels was consistently greater under the straw and gauze than on the bare ground and that the length of time during which moisture content of the surface soil was above the calculated W. C. was greatest under the straw litter.
3. Germination and emergence of grass seedlings was increased from 4 to more than 20 times over that on the bare ground by the various surface-soil treatments.

LITERATURE CITED

1. BRIGGS, LYMAN J., and MCLANE, JOHN W. The moisture equivalent of soils. U. S. D. A. Bur. Soils Bul. 45. 1907.
2. ———, and SHANTZ, H. L. The wilting coefficient for different plants and its indirect determination. U. S. D. A. Bur. Plant Ind. Bul. 230. 1912.

3. GLENDENING, GEORGE E. Development of seedlings of *Heteropogon contortus* as related to soil moisture and competition. Bot. Gaz., 102:684–698. 1941.
4. GRIFFITH, D. A protected stock range in Arizona. U. S. D. A. Bur. Plant Ind. Bul. 177. 1910.
5. GRISWOLD, SYLVIA M. Effect of alternate moistening and drying on germination of seeds of western range plants. Bot. Gaz., 98:243–269. 1936.
6. MCGINNIES, W. G., and ARNOLD, JOSEPH F. Relative water requirement of Arizona range plants. Ariz. Agr. Exp. Sta. Tech. Bul. 80. 1939.
7. THORNBER, J. J. The grazing ranges of Arizona. Ariz. Agr. Exp. Sta. Bul. 65. 1910.
8. WOOTON, E. O. Carrying capacity of grazing ranges in southern Arizona. U. S. D. A. Bul. 367. 1916.
9. YOUNGS, F. O., *et al.* Soil survey of the Tucson area, Arizona. U. S. D. A. Bur. Chem. and Soils, Soil Surveys Ser. 1931, Rpt. 19. 1936.

A COMPARISON OF LINE TRANSECTS AND PERMANENT QUADRATS IN EVALUATING COMPOSITION AND DENSITY OF PASTURE VEGETATION OF THE TALL PRAIRIE GRASS TYPE[1]

KLING L. ANDERSON[2]

PERMANENT meter-square quadrats, located in representative areas, have been used in recording vegetative changes in density and succession of vegetation on the experimental native tall grass pastures at Manhattan, Kan., since this type of work was started more than 25 years ago. There admittedly exists opportunity for personal bias in the locating of permanent quadrats, and where large pastures are being sampled it is generally not possible to study a sufficient number of quadrats to give a truly representative sample of the vegetation. Furthermore, a given area in which a quadrat is placed may not remain representative of the pasture due to conditions over which the investigator has no control, or due, perhaps, to the experimental conditions set up to influence the density or botanical composition of the pasture vegetation. Where comparisons between pastures are being made, it is necessary that the samples be representative of the pasture as a whole.

The actual mapping is always time-consuming because the individual culms as well as the areas occupied by clumps of vegetation must be carefully drawn into the small scale quadrat map with the aid of a pantograph or directly by means of numerous wires crossing the quadrat. It has been found that an experienced worker can list-chart five to eight meter-square quadrats in a day, depending on the type and density of vegetation. The marking stakes locating the quadrats are frequently trampled and destroyed by livestock, however, and this sometimes makes it necessary to spend additional time searching for the quadrats. All of these things tend to make this method slow and therefore costly.

The line-transect or line-interception method of sampling described by Canfield[3] and Savage[4] for sampling range vegetation is more rapid than the quadrat method. In these pastures two workers were able to obtain from five to seven transect readings in an hour, making it possible to secure a much larger number of samples in a given length of time and therefore cover the area more completely. Furthermore, these sample plots are long and narrow rather than square, which is

[1]Contribution No. 332 from the Department of Agronomy, Kansas State Agricultural Experiment Station, Manhattan, Kan., and the Division of Forage Crops & Diseases, U. S. Dept. of Agriculture, cooperating. Received for publication April 6, 1942.

[2]Assistant Professor of Pasture Management and Collaborator, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.

[3]CANFIELD, R. H. Application of the line interception method in sampling range vegetation. Jour. Forestry, 39:388–394. 1941.

[4]SAVAGE, D. A. The line-transect method. An improved method of studying native range vegetation. Special mimeographed memorandum of September 15, 1940.

considered advantageous in certain plot technic. In view of these considerations it was deemed advisable to sample two pastures, on which meter-square quadrats had been under observation since 1927, by means of 10-meter line-transects for comparison with the quadrats. This was done in July, 1940, shortly after the quadrat counts had been made.

MATERIAL AND METHODS

The quadrats in this experiment are neither listed nor charted but in making the readings a combination list-chart method is used, listing individual culms and charting the basal area of tufts or clumps of vegetation in square cm. A single culm is assigned a value of 1 square cm. Line-transect readings are obtained by recording all vegetation that is found in direct contact with a 10-meter length of $\frac{3}{32}$-inch steel brake cable stretched tightly as near the ground as possible. Clumps of vegetation are measured in cm along the cable as it crosses the base of the clump ignoring open spaces of less than 1 cm because when the parts of a plant at ground surface level are no more than 1 cm apart they are considered in this study to represent solid ground cover. A new clump is started wherever there occurs a space of more than 1 cm in which no vegetation touches the wire. Individual culms 1 cm or more from others along the cable are assigned a value of 1 which is added to the clump measurements for each species; and since they receive a value of 1 cm along the cable, they may be assumed to occupy 1 square cm of area as in the quadrat readings described above. Where culms are closer than 1 cm, they are measured as a clump.

An attempt was made at first to include all single culms within a strip 1 cm wide in the transect reading, but it was not always possible to judge quickly and accurately whether or not a culm fell within this strip. In order to make sampling as rapid as possible, the necessity for measuring to determine whether or not a culm should be included was eliminated by excluding from the counts all individual culms which did not touch the wire stretched tightly at ground level. This also eliminated any variability that might result from differences in the ability of workers to estimate the distance of culms from the wire, or from differences in the ability of any given worker to make such estimates uniformly under changing light conditions.

The values obtained by these methods of sampling are not only estimates of vegetative composition, but since they are taken as area measurements they are also estimates of density in terms of basal ground cover. The values obtained in the line-transect readings are given in cm along a 1,000-cm (10 meters) wire and are equivalent to square cm in a 1,000 square cm plot. They can therefore easily be converted into percentage of density by moving the decimal one place to the left. The resulting value would then represent the percentage of the total ground surface occupied by the basal portion of the plants.

The quadrat measurements are also given in terms of square cm, but since each quadrat occupies 1 square meter or 10,000 square cm, it is necessary to move the decimal two places to the left to convert to density in percentage of ground surface occupied.

If the transect is assumed to be a plot of 1 by 1,000 cm, it should contain approximately 1/10 the vegetative population found in the quadrat. That this is actually the case is shown in Table 5 where it will be seen that the average total population of the quadrats/10 in pasture No. 1 was 116.8 and that of the transects 106.3. The agreement in pasture No. 2 was not so close, the average for the

transects exceeding that of the quadrats/10 by 35.9. The greater density of vegetation in pasture No. 2 is clearly shown by both methods of measurement, however.

The transects were located in seven series extending in reasonably straight lines across each pasture. No attempt was made to choose the location of any particular transect within a series, except to stop for each new sampling unit at a distance of 70 paces from the last point sampled. The workers simply crossed the pasture, driving the first stake of each new location 70 paces from the last stake of the previous point sampled. The stake was driven where the seventieth pace fell without regard to soil condition or to vegetative cover. After the length of the pasture had been sampled in this manner by a series of transects, the workers moved approximately one-eighth the distance across the pasture and repeated the operation until all seven series of line-transects had been recorded.

RESULTS

In pasture No. 1, comprising 1,058 acres, the seven series of line-transects included 195 individual readings, or 1 to each 5.43 acres, while in pasture No. 2 with an area of 111 acres there were also seven series including 56 individual transects, or 1 to each 1.98 acres. The readings obtained are summarized in Tables 1 and 2 which show the average reading for each species per transect within series of transects. The numbers of individual transects per series are also shown.

Tables 3 and 4 show the actual quadrat readings from these pastures for the season of 1940. In pasture No. 1 there are 25 permanent quadrats, or an average of 1 for each 42.3 acres, and in pasture No. 2 there are 15 quadrats, an average of 1 for each 7.4 acres. These have all been examined at intervals of 1 to 3 years since 1927 to obtain a record of vegetative succession, and a few were studied as early as 1920.

Table 5 summarizes both quadrat and transect data, bringing the two together for comparison, both as to actual numbers of plants of each species and percentage of total population.

Figs. 1 and 2 compare graphically the values obtained in the quadrats with those obtained by means of line-transects. In these two charts the relative importance of each species is shown as the percentage of the total plant population, thus making possible a direct visual comparison between quadrats and line-transects.

As a further comparison of the line-transect and the meter-square quadrat in sampling the tall grass pastures, the 15 meter-square quadrats in pasture No. 2 were sampled with the line-transect in 1940 shortly after having been studied by the conventional list-chart method. This was accomplished by reading 10 1-meter transect lines across the area occupied by the quadrat, 5 in each direction at regularly spaced intervals, thus taking approximately one-tenth of the total area of the quadrat as a sample. These comparisons by species are shown numerically in Table 6 and the relationship between the two methods is shown graphically in Fig. 3.

When measurements made on identical areas are compared, both methods are found to give similar estimates of the plant population (Table 6). There is a tendency for the transect readings to give a

TABLE I.—*Average plant population in 195 line transects, pasture No. 1, 1,058 acres.**

Series No.	No. of transects per series	*Andropogon furcatus*	*A. scoparius*	*Panicum virgatum*	*Sorghastrum nutans*	*Bouteloua curtipendula*	*B. hirsuta*	*B. gracilis*	*Buchloe dactyloides*	*Sporobolus heterolepis*	*S. asper*	*S. cryptandrus*	*Chloris verticillata*	*Poa pratensis*	Other perennial grasses	Annual grasses	*Carex* spp.	Annual weeds	Perennial weeds	Av. total plant population per transect
I.......	27	25.9	8.6	2.0	1.9	19.3	1.7	3.3	22.3	0.1	3.3	7.9	2.9	—	2.4	6.4	4.5	1.6	5.1	119.0
II......	28	25.6	13.9	0.3	1.4	13.6	2.2	4.2	15.3	0.8	1.2	9.4	5.5	2.4	0.1	3.7	3.6	2.1	3.0	108.5
III.....	28	19.3	8.7	0.2	1.6	24.1	1.0	3.0	23.7	0.2	0.4	10.5	6.8	Tr.	3.1	7.9	2.1	3.7	2.9	112.3
IV......	27	23.7	9.0	0.2	3.4	23.9	2.1	2.3	9.4	—	1.2	1.5	1.7	—	0.9	1.3	4.6	2.6	4.0	91.9
V.......	28	19.3	4.3	0.2	1.2	23.4	1.8	1.8	22.9	—	1.3	10.8	2.3	Tr.	2.3	15.0	4.6	2.7	2.2	115.0
VI......	29	22.4	4.3	0.5	1.2	22.9	1.9	2.1	26.9	—	0.4	8.2	1.6	Tr.	2.6	10.1	3.6	1.6	2.6	113.1
VII.....	28	15.3	3.2	0.4	0.5	23.5	1.6	0.4	15.4	—	0.4	3.7	3.4	—	0.9	8.4	2.1	1.4	3.4	84.0
Av..........		21.6	6.8	0.5	1.6	21.5	1.8	2.4	19.5	0.2	1.2	7.5	3.1	0.4	1.6	7.6	3.6	2.2	3.3	106.3
% of total population.....		20.3	6.4	0.5	1.5	20.4	1.7	2.3	18.3	0.2	1.1	7.0	2.9	0.3	1.5	7.1	3.4	2.1	3.1	100.0

*Average number of cm occupied by each species along the transect wire is given for each series of transects. Line transect 10 meters in length.

TABLE 2.—*Average plant population in 56 line transects, pasture No. 2, 111 acres.**

Series No.	No. of transects per series	*Andropogon furcatus*	*A. scoparius*	*Panicum virgatum*	*Sorghastrum nutans*	*Bouteloua curtipendula*	*B. hirsuta*	*B. gracilis*	*Buchloe dactyloides*	*Sporobolus heterolepis*	*S. asper*	*S. cryptandrus*	*Chloris verticillata*	*Poa pratensis*	Other perennial grasses	Annual grasses	*Carex* spp.	Annual weeds	Perennial weeds	Av. total plant population per transect
I.......	7	75.1	11.9	3.4	5.3	30.6	0.3	0.0	35.9	7.0	3.4	30.9	0.6	—	1.4	—	9.1	—	2.3	217.1
II......	7	59.1	16.0	0.4	0.7	29.3	1.6	0.4	0.1	6.9	2.3	2.1	0.0	—	1.4	1.6	4.0	0.4	10.9	137.3
III.....	7	44.4	16.0	2.9	1.3	51.1	3.6	0.1	26.3	8.1	0.6	11.1	6.7	—	0.6	—	7.7	—	4.9	185.3
IV......	7	59.9	12.9	4.7	5.3	30.1	1.1	0.1	2.0	2.6	2.4	9.4	3.0	—	1.7	11.3	17.6	1.7	5.1	171.0
V.......	7	51.4	22.3	0.6	4.3	37.0	5.0	0.7	4.4	4.4	0.4	2.1	0.1	—	0.3	3.1	5.7	0.6	4.1	142.3
VI......	11	57.4	12.6	2.2	4.9	40.9	4.2	1.1	8.6	2.1	4.3	1.5	1.2	—	2.5	2.7	6.2	0.5	2.4	244.0
VII.....	10	59.5	17.8	8.1	6.4	44.2	1.2	11.0	60.1	3.0	3.0	68.7	4.0	0.2	3.6	25.7	14.3	2.4	6.6	339.8
Av...........		58.1	15.5	3.4	4.2	38.2	2.5	2.4	20.5	4.6	2.5	19.5	2.2	Tr.	1.8	7.1	9.3	0.9	5.1	197.8
% of total.....		29.4	7.9	1.7	2.1	19.3	1.3	1.2	10.3	2.3	1.3	9.9	1.1	Tr.	0.9	3.6	4.7	0.4	2.5	100.0

*Average number of cm occupied by each species along the transect wire is given for each series of transects. Transects 10 meters in length.

TABLE 3.—*Record of quadrat readings, pasture No. 1, season of 1940.**

Quadrat No.	*Andropogon furcatus*	*A. scoparius*	*Panicum virgatum*	*Sorghastrum nutans*	*Bouteloua curtipendula*	*B. hirsuta*	*B. gracilis*	*Buchloe dactyloides*	*Sporobolus heterolepis*	*S. asper*	*S. cryptandrus*	*Chloris verticillata*	*Poa pratensis*	Other perennial grasses	Annual grasses	*Carex* spp.	Annual weeds	Perennial weeds	Total
1	43	—	—	76	353	286	34	—	—	—	—	36	—	—	—	3	—	53	884
2	142	—	—	—	—	—	—	186	—	—	218	—	—	—	991	—	—	24	1,561
3	178	28	6	49	294	362	113	—	—	—	—	—	—	—	—	—	—	8	1,038
4	309	34	—	53	368	4	23	194	51	—	—	—	—	19	—	90	1	67	1,213
5	278	1	—	—	—	12	65	—	—	2	26	—	—	113	37	87	4	119	744
6	273	61	7	—	535	30	122	—	3	4	—	—	—	20	7	112	9	29	1,212
7	116	60	7	9	356	7	9	—	—	—	—	—	—	1	—	—	—	9	574
8	412	15	9	22	41	—	2	16	—	—	239	—	—	—	137	64	2	32	991
9	294	136	18	9	254	25	—	—	—	—	3	—	—	—	—	40	—	40	819
10	285	15	—	—	135	—	—	—	—	24	11	—	—	—	—	17	—	13	500
11	154	70	—	75	92	22	—	3	—	—	94	—	—	47	3	4	—	38	602
12	217	—	—	—	42	—	—	1,832	—	—	469	1	—	1	22	42	9	74	2,709
13	485	20	—	42	179	17	—	3	—	—	13	—	—	—	—	56	—	18	833
14	133	—	5	—	351	215	6	—	—	—	—	—	—	—	—	—	—	3	713
15	90	65	27	—	739	38	9	—	—	—	—	—	—	—	—	—	—	46	1,014
16	141	13	7	—	89	—	—	933	—	17	405	521	—	4	387	163	1	34	2,715
17	11	—	—	—	—	—	—	1,828	—	—	158	56	—	144	255	10	20	28	2,511
18	31	218	—	—	641	25	36	103	—	—	283	—	—	8	731	12	—	35	2,123
19	156	5	—	—	577	63	8	1	—	—	—	—	—	—	—	—	—	19	829
20	85	—	—	—	2	—	—	204	—	—	614	11	—	—	671	43	14	15	1,659
21	374	14	1	17	237	56	50	—	—	—	—	—	—	2	—	—	—	31	782
22	273	—	3	—	224	240	—	2	—	—	—	10	—	7	—	1	—	53	813
23	331	15	8	—	237	9	—	—	—	—	6	—	—	—	—	74	—	24	704
24	535	—	—	—	141	216	—	—	—	—	—	—	—	—	—	—	—	7	899
25	272	25	10	—	370	24	34	—	1	—	—	—	—	—	—	5	—	9	750
Total	5,618	795	108	352	6,257	1,651	511	5,305	55	47	2,539	635	—	366	3,241	823	60	828	29,191
Av. /10	22.5	3.2	0.4	1.4	25.0	6.6	2.0	21.2	0.2	0.2	10.2	2.5	—	1.5	13.0	3.3	0.2	3.3	116.8
% of total	19.2	2.7	0.4	1.2	21.4	5.7	1.8	18.2	0.2	0.2	8.7	2.2	—	1.3	11.1	2.8	0.2	2.8	—

*Number of square cm occupied by each species, including individual culms each of which is assigned a value of 1 cm.

TABLE 4.—*Record of quadrat readings, pasture No. 2, season of 1940.**

Quadrat No.	*Andropogon furcatus*	*A. scoparius*	*Panicum virgatum*	*Sorghastrum nutans*	*Bouteloua curtipendula*	*B. hirsuta*	*B. gracilis*	*Buchloe dactyloides*	*Sporobolus heterolepis*	*S. asper*	*S. cryptandrus*	*Chloris verticillata*	*Poa pratensis*	Other perennial grasses	Annual grasses	*Carex* spp.	Annual weeds	Perennial weeds	Total
1........	211	606	142	87	426	14	8	—	—	—	—	—	—	—	—	—	—	11	1,505
2........	631	255	—	88	301	135	14	—	—	—	11	—	—	—	—	230	—	50	1,715
3........	1,043	151	—	58	199	20	11	—	90	46	—	—	—	11	—	5	—	22	1,656
4........	306	243	—	—	364	184	10	—	—	—	44	—	—	33	—	16	—	24	1,225
5........	945	102	—	110	582	134	3	—	—	—	—	—	—	1	—	—	—	10	1,886
6........	527	32	—	47	289	65	47	—	—	—	—	—	—	—	—	—	—	15	1,022
7........	328	—	—	—	862	127	—	—	—	—	742	—	—	—	—	—	—	2	2,061
8........	300	83	—	—	434	180	198	—	—	—	—	—	—	2	—	—	—	31	1,228
9........	591	143	5	147	451	52	23	—	—	—	—	—	—	1	—	1	—	—	1,414
10........	666	—	—	—	20	—	—	—	—	—	1,304	28	—	8	6	9	—	—	2,041
11........	787	3	24	—	580	69	43	—	—	—	—	—	—	2	—	1	—	7	1,516
12........	149	607	—	29	223	444	60	—	81	46	—	—	—	—	—	120	—	26	1,875
13........	240	585	—	4	327	166	65	—	78	59	86	—	—	17	—	18	—	25	1,670
14........	393	504	—	26	331	64	23	—	—	4	—	—	—	—	—	345	—	82	1,772
15........	324	915	—	26	138	83	11	—	—	—	—	—	—	26	—	167	—	17	1,707
Total......	7,441	4,319	171	622	5,527	1,737	516	—	249	155	2,187	28	—	101	6	912	—	322	24,293
Av./10.....	49.6	28.8	1.1	4.1	36.9	11.6	3.4	—	1.7	1.0	14.6	0.2	—	0.7	Trace	6.1	—	2.1	161.9
% of total..	30.6	17.8	0.7	2.5	22.8	7.2	2.1	—	1.0	0.6	9.0	0.1	—	0.4	Trace	3.7	—	1.3	—

*Number of square cm occupied by each species, including individual culms each of which is assigned a value of 1 cm.

TABLE 5.—*Summary of comparison of quadrat vs. transect data.*

Species	No. of square cm occupied*				% of total population			
	Pasture I		Pasture II		Pasture I		Pasture II	
	Quadrats (av./10)	Transects (av.)	Quadrats (av./10)	Transects (av.)	Quadrats	Transects	Quadrats	Transects
Andropogon furcatus	22.5	21.6	49.6	58.1	19.2	20.3	30.6	29.4
A. scoparius	3.2	6.8	28.8	15.5	2.7	6.4	17.8	7.9
Panicum virgatum	0.4	0.5	1.1	3.4	0.4	0.5	0.7	1.7
Sorghastrum nutans	1.4	1.6	4.1	4.2	1.2	1.5	2.5	2.1
Bouteloua curtipendula	25.0	21.5	36.9	38.2	21.4	20.4	22.8	19.3
B. hirsuta	6.6	1.8	11.6	2.5	5.7	1.7	7.2	1.3
B. gracilis	2.0	2.4	3.4	2.4	1.8	2.3	2.1	1.2
Buchloe dactyloides	21.2	19.5	—	20.5	18.2	18.3	—	10.3
Sporobolus heterolepis	0.2	0.2	1.7	4.6	0.2	0.2	1.0	2.3
S. asper	0.2	1.2	1.0	2.5	0.2	1.1	0.6	1.3
S. cryptandrus	10.2	7.5	14.6	19.5	8.7	7.0	9.0	9.9
Chloris verticillata	2.5	3.1	0.2	2.2	2.2	2.9	0.1	1.1
Poa pratensis	—	0.4	—	Trace	—	0.3	—	Trace
Other perennial grasses	1.5	1.6	0.7	1.8	1.3	1.5	0.4	0.9
Annual grasses	13.0	7.6	Trace	7.1	11.1	7.1	—	3.6
Sedges	3.3	3.6	6.1	9.3	2.8	3.4	3.7	4.7
Annual weeds	0.2	2.2	—	0.9	0.2	2.1	—	0.4
Perennial weeds	3.3	3.3	2.1	5.1	2.8	3.1	1.3	2.5
Total	116.8	106.3	161.9	197.8				

*Includes single culms each assigned a value of 1 square cm.

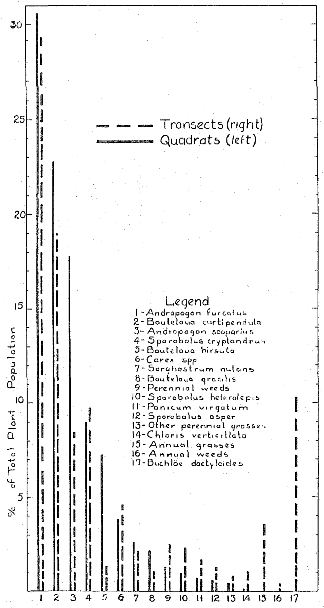


FIG. 1.—A comparison of randomized line-transects and permanent quadrats in native tall grass pasture, Casements pasture No. 1.

value slightly higher than one-tenth the quadrat in most of the 15 quadrat areas sampled, but it will be recalled that in pasture No. 2 the randomized line-transects gave a higher estimate of total density of

vegetation than did the quadrats, while the opposite was true in pasture No. 1 where the total density was less and the population was to a greater extent made up of the shorter grasses.

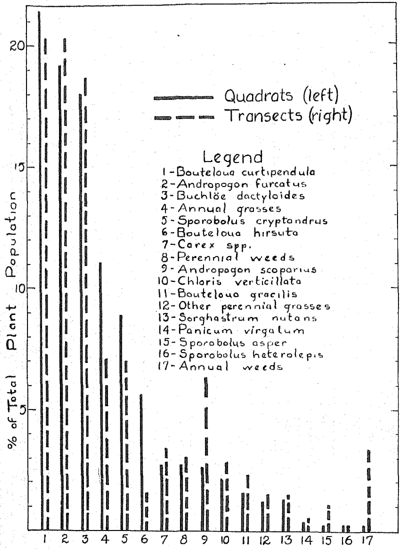


FIG. 2.—A comparison of randomized line-transects and permanent quadrats in native tall grass pasture, Casements pasture No. 2.

The actual values for each species are probably less important for purposes of comparison than are the relationships between the two methods shown in Fig. 3. Quadrat values plotted against transect

values for individual species show that the two methods agree closely in estimating the plant population of the area sampled.

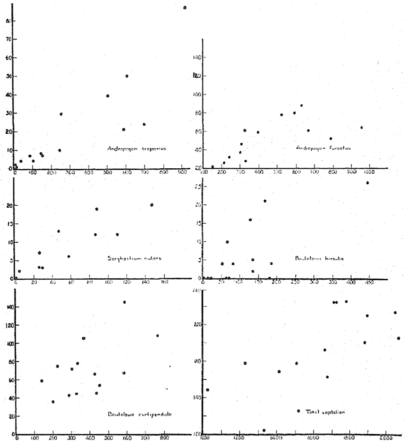


FIG. 3.—Correlation of plant population values in permanent meter-square quadrats and those obtained by sampling the quadrat with 10 transect lines, 5 in each direction. The quadrat values on horizontal axis; transect values on vertical axis.

To obtain additional information on the accuracy with which the vegetation had been sampled by the line-transects, analyses of variance were calculated for three species, *viz.*, *Andropogon furcatus*, *A. scoparius*, and *Bouteloua curtipendula*, in each pasture. These analyses are simply a comparison of the variability between series of transect lines to that within series, and indicate, as would be expected, that the series of transects are not significantly different from one another, the only exception being *A. scoparius* in pasture No. 1. This species, as shown in Table 1, varied considerably from series to series, the numbers being especially low in series III, V, VI, and VII

TABLE 6.—*Direct comparison of quadrat and line transect readings made on the same area by crossing the permanent quadrat with 10 transect readings, 5 in each direction.*

Quadrat No.	*Andropogon furcatus*		*A. scoparius*		*Panicum virgatum*		*Sorghastrum nutans*		*Bouteloua curtipendula*		*B. hirsuta*		*B. gracilis*		*Sporobolus heterolepis* and *S. asper*		*S. cryptandrus*		*Carex* spp.		Weeds		Total vegetation*	
	Q†	T†	Q	T	Q	T	Q	T	Q	T	Q	T	Q	T	Q	T	Q	T	Q	T	Q	T	Q	T
1	211	26	606	50	142	24	87	12	426	66	14	—	8	—	—	—	—	—	—	—	11	—	1,505	178
2	631	88	255	29	—	—	88	19	301	72	135	2	14	—	—	—	11	2	230	27	50	8	1,715	244
3	1,043	135	151	7	—	—	58	6	199	36	20	—	11	—	136	2	—	—	5	—	22	1	1,656	192
4	306	46	243	10	—	—	—	—	364	105	184	4	10	—	—	—	44	7	16	2	24	1	1,225	177
5	945	63	102	4	—	—	110	12	582	144	134	5	3	—	—	—	—	—	—	—	10	4	1,886	230
6	527	78	32	4	—	—	47	13	289	43	65	10	47	—	—	—	—	—	—	—	15	—	1,022	148
7	328	28	—	—	—	—	—	—	862	108	127	16	—	—	—	—	742	53	—	—	2	—	2,061	206
8	300	37	83	7	—	—	—	—	434	45	180	—	198	14	—	—	—	—	—	—	31	1	1,228	104
9	591	80	143	8	5	—	147	20	451	54	52	4	23	2	—	—	—	—	1	—	—	—	1,414	168
10	666	61	—	—	—	—	—	—	20	—	—	—	—	—	—	—	1,304	158	9	2	—	—	2,041	234
11	787	52	3	2	24	1	—	—	580	67	69	—	43	2	—	—	—	—	1	—	7	1	1,516	125
12	149	22	697	28	—	—	29	3	223	75	444	26	60	11	127	—	—	—	120	28	26	3	1,875	200
13	240	32	585	16	—	—	4	2	327	45	166	21	65	2	137	18	86	8	18	2	25	8	1,670	162
14	393	59	504	40	—	—	26	7	331	78	64	—	23	—	4	—	—	—	345	43	82	17	1,772	245
15	324	61	915	87	—	—	26	3	138	59	83	4	11	—	—	—	—	—	167	17	17	4	1,707	244

*Total vegetation includes *Chloris verticillata*, *Poa pratensis*, other perennial grasses, and annual grasses not shown in detail because of the fact that they occur in small amounts.
†Q = Quadrat; T = Line transect.

Series V, VI, and VII are in the south half of the pasture, and an examination of the area shows that this part, being nearer to the ranch headquarters, is grazed more heavily than the north half. *A. scoparius* had been seriously depleted throughout the bluestem area by the drought of the middle 1930's and in pasture No. 1 it had suffered greater injury in the more closely grazed south half than elsewhere in the pasture. It had also recovered more slowly along the south side, and while this may also be true to a limited extent for some of the other species, it is certainly not nearly so pronounced, as an examination of the data will show. Series VII in pasture No. 1 contains a slightly smaller amount of *A. furcatus* than the other series, and the south half of the pasture appears generally to have less than the north half, but these differences cannot be shown to be statistically significant.

In pasture No. 2, the variability is greater within than between series in the three species studied statistically, and significantly so in *Andropogon scoparius*. This pasture is smaller (111 acres), and since it has been grazed more conservatively than pasture No. 1 for many years,[5] it is now a better and more uniform pasture, if pastures can be said to be uniform. It would probably be more accurate to say that the variability in species composition and density is more nearly uniform throughout pasture No. 2 than it is in pasture No. 1. The analyses lend support to these deductions.

To study the variability in pasture No. 1 in still greater detail, the series were broken down into four parts each, thus dividing the seven series of line-transects into 28 sub-series which may be grouped in four rows of seven sub-series each across the pasture, as shown in Table 7. In none of the three species do the sub-series totals differ significantly, but it is possible to show significant differences between individual sub-series in *Andropogon furcatus* and highly significant differences in *A. scoparius*, while the sub-series differences in *Bouteloua curtipendula* are not significant. These data lend support to observations as to actual conditions in the pasture and make it possible to compare the various parts of the pasture with one another in a statistical way, a procedure not possible heretofore. The line-transects appear to give a more accurate picture of the condition of the pasture than the quadrats and may therefore be considered more useful in estimating density or vegetative composition of the area as a whole.

DISCUSSION

The close agreement between quadrat and line-transect values for most species in contrast with the rather wide discrepancies that occur in a few important species is a striking feature of this comparison of sampling methods. Since the two methods agree so closely, they both appear to be fairly reliable samples of the true plant population. This agreement is further emphasized by the close relationship between the two methods of sampling shown in Fig. 4 in which transect values

[5]ANDERSON, K. L. Deferred grazing of bluestem pastures. Kans. Agr. Exp. Sta. Bul. 291. 1940.

are plotted against the quadrat values for each important species in each pasture.

TABLE 7.—*Sub-series totals of three species of tall grass as measured by 195 line-transects in pasture No. 1.**

Sub-series No.	Series No.							Sub-series totals
	I	II	III	IV	V	VI	VII	
				Andropogon furcatus				
1	262	182	158	195	161	204	107	1,269
2	177	225	157	98	114	203	140	1,114
3	165	168	126	185	145	135	132	1,056
4	94	141	100	162	121	108	50	776
Series totals	698	716	541	640	541	650	429	4,215
				Andropogon scoparius				
1	99	19	33	42	8	26	20	347
2	39	126	11	50	17	55	30	328
3	33	106	55	101	35	27	29	386
4	62	139	30	50	61	17	10	369
Series totals	233	390	129	243	121	125	89	1,330
				Bouteloua curtipendula				
1	174	100	122	155	174	186	179	1,090
2	166	112	287	184	123	126	155	1,153
3	99	79	130	146	209	103	194	960
4	81	90	135	154	148	249	129	986
Series totals	520	381	674	639	654	664	657	4,189

*Number of cm along the quadrat wire occupied by vegetation. Includes individual culms, each assigned a value of 1 cm.

The agreement between transects and quadrats appears to be closer in pasture No. 1 than in pasture No. 2, and seems to indicate that the former was more adequately sampled. This is probably not the case, however, since in pasture No. 1 there was an average of but 1 quadrat to each 42.3 acres and 1 transect to each 5.43 acres; while in pasture No. 2 there was a quadrat for each 7.4 acres and a transect for each 1.98 acres. The apparent difference is probably due to the wide discrepancies between quadrat and transect estimates of *Buchloe dactyloides* and *Bouteloua hirsuta* found in pasture No. 2 (Fig. 4). These species are not uniformly distributed throughout the pasture but tend to occur in limited areas and may not have been properly sampled by the quadrats. It appears that, while the quadrats failed entirely to sample *Buchloe dactyloides* in pasture No. 2, they have shown excessively large amounts of *Bouteloua hirsuta*. *Andropogon scoparius* is also shown in large amounts by the quadrats.

In pasture No. 1 the quadrats and transects fail to show close agreement in *Bouteloua hirsuta*, *Andropogon scoparius*, and the annual species. As in pasture No. 2, the transects show a much smaller population of *B. hirsuta* than is indicated by the quadrats. *A. scoparius*,

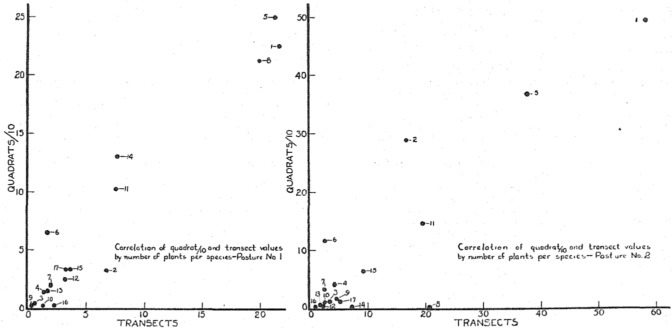


FIG. 4.—Relationship of quadrat and transect values by species. Quadrat values plotted on horizontal axis and transect values on vertical axis. 1, *Andropogon furcatus;* 2, *Andropogon scoparius;* 3, *Panicum virgatum;* 4, *Sorghastrum nutans;* 5, *Bouteloua curtipendula;* 6, *Bouteloua hirsuta;* 7, *Bouteloua gracilis;* 8, *Buchloe dactyloides;* 9, *Sporobolus heterolepis;* 10, *Sporobolus asper;* 11, *Sporobolus cryptandrus;* 12, *Chloris verticillata;* 13, other perennial grasses; 14, annual grasses; 15, *Carex* sp.; 16, annual weeds; 17, perennial weeds.

on the other hand, has behaved differently, being shown in greater amounts by the transects than by quadrats in pasture No. 1. *Buchloe dactyloides* is shown in practically equal amounts by both methods of sampling in this pasture, where it is one of the predominant species and is widely distributed.

It would appear from these data that species which are distributed rather uniformly throughout the entire pasture are likely to be recorded in approximately equal amounts by both methods of sampling, but species that tend to be confined to small, rather isolated areas in the pasture are less likely to appear in the quadrats than in the transects. Some of these occur in very dense stands in the small areas they do occupy, and if a quadrat should be located in such a place the importance of the particular species would tend to be overemphasized. The transects, being much more numerous and scattered throughout the pasture at random, sample these small areas without overemphasizing their relative importance in the pasture population.

This failure of the quadrats to sample a species properly may be illustrated by *Buchloe dactyloides* in pasture No. 2. Deferred grazing has permitted *Andropogon furcatus* and *A. scoparius* to increase greatly in density throughout this pasture, crowding *B. dactyloides* and other short grass species to such an extent that these remain in abundance only on ridge-tops, and even there they are interspersed with the taller types. The quadrats, which now show no *B. dactyloides*, formerly contained a fair amount of this species, but there was a steady decline from 1929 until about 1938 after which no more was seen in the particular areas sampled by the quadrats. The quadrats have shown the disappearance of *B. dactyloides* in the particular areas they occupy but fail to show that it still exists in considerable quantities elsewhere in the pasture. *Bouteloua hirsuta*, conversely, is shown in greater density by quadrats than by transects, probably due to the fact that, while this species is more or less confined to local areas, especially along the upper slopes, many of the quadrats are located there and would therefore be expected to show a high population of *B. hirsuta*. It is probable that the quadrat estimate of density for this species is too high.

Andropogon scoparius is considerably less abundant in pasture No. 1 than in pasture No. 2, but it appears to be about as uniformly distributed in either pasture as any of the other species. *A. scoparius* was seriously depleted in both pastures by the droughts of 1934 and 1936, but since that time it has increased more rapidly in pasture No. 2 because of the deferred grazing in this pasture. Referring to Tables 1 and 2, it will be seen that the density of this species as estimated by transects is almost one-half as great in pasture No. 1 as in pasture No. 2, while the quadrats show it to be only one-ninth as great (Tables 3 and 4). Here again, a knowledge of the pastures will lead to the conclusion that the transects have given a more accurate estimate of the difference between these two pastures and of the relative importance of *A. scoparius* in comparison to the other species (Fig. 5).

The annual weeds and grasses are shown in greater relative amounts by transects in both pastures. The quadrats show no annual weeds

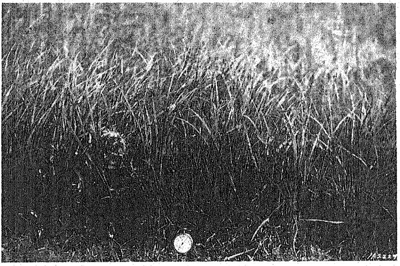


FIG. 5.—Tall grass prairie of the type reported in this study. Dominant grasses are *Andropogon furcatus* and *A. Scoparius*, but many other grasses and weeds are present in varying amounts. (See tables showing plant populations.)

and only a trace of annual grasses in pasture No. 2, while the transects show the annual weeds to comprise 0.4% and annual grasses 3.6% of the total population. This pasture has a very low weed and annual grass population, but it is certainly higher than shown by quadrat readings, and probably somewhat higher in the case of annual weeds than shown by the transects. In pasture No. 1 the quadrats indicate that only 0.2% of the population consists of annual weeds, while the transects show this amount to be 2.1%. The quadrats, therefore, show hardly more than a trace of annual weeds in pasture No. 1, suggesting that it is as free of weeds as pasture No. 2. Actually, the two are quite different, pasture No. 2 having much the smaller weed population because it has been grazed so much more conservatively. The two methods agree fairly closely in estimating the annual grass in pasture No. 1, the transects showing it to comprise 7.1% and the quadrats 11.1% of the total population. Observation of the pasture will show that neither estimate can be far wrong.

The failure of the quadrats to give a true estimate of the population and density is apparently due to the lack of sufficient numbers of samples, but the cost of obtaining permanent, meter-square quadrat samples in large enough numbers to be representative of the area as a whole would be prohibitive. Another important factor which favors the transects as being more representative of the pasture as a whole is the fact that they are located at random in the pasture.

SUMMARY AND CONCLUSIONS

Comparisons between the permanent quadrat and the randomized line-transect method of sampling pasture vegetation were made in

native tall grass pastures near Manhattan, Kan., in 1940 in order to determine whether the line-transect method would be as satisfactory as the permanent quadrat method in determining composition and density of vegetation. The line-transect method is much more rapid and easier, therefore less costly.

In general, the two methods gave comparable results, agreeing closely in most instances but showing some discrepancy in certain species. These discrepancies seem, for the most part, to be due to failure of the quadrats to sample the vegetation adequately but were not great enough in most cases to be serious. Failure of the quadrats to sample the vegetation adequately is due primarily to the fact that it has not been possible to maintain a sufficient number of quadrats. In addition, the permanent sample plots, located arbitrarily in areas that appear to be representative, may not represent the pasture as a whole. Transects, on the other hand, are randomized to eliminate personal bias in selecting the location of the sample areas. The transects appear to give estimates of the pasture population as good as or better than the quadrats, although it is possible that the amount of *Buchloe dactyloides* in pasture No. 2 was exaggerated by the transects and the annual weeds somewhat underestimated.

When comparisons were made on identical areas, the agreement was even closer than in the measurement made on a pasture basis.

In view of the advantages found in the line-transect method, it is to be tested further on these pastures and will probably be substituted for the quadrat method if it should continue to prove satisfactory in future comparisons.

WASTE POND PHOSPHATE COMPARED WITH ROCK PHOSPHATE AND SUPERPHOSPHATE AS A FERTILIZER[1]

GARTH W. VOLK[2]

THE use of waste pond phosphate as a fertilizer for various crops has become rather widespread in the southeastern region of the United States. Data on the availability of the phosphorus in waste pond phosphate for plant use are very limited. The availability may vary with the crops grown since the ability of different plants to feed on the more insoluble raw phosphates varies appreciably.

McCool (3)[3] found that Tennessee brown rock phosphate and waste pond phosphate did not differ significantly in the production of various plants whether tested in the greenhouse or in the field. Fraps (1) conducted a number of pot tests comparing waste pond phosphate with finely ground rock phosphate and superphosphate. His results showed that the availability of phosphoric acid in waste pond and rock phosphate was considerably lower than that in superphosphate, and its availability seemed to be lower in neutral and basic soils than in acid soils.

Hartwell and Damon (2) found that rock phosphate used at 2.3 times the P_2O_5 rate was equal to triple superphosphate but not equal to Thomas slag, acid phosphate, or ground bone. They found that cabbage, rape, and rutabagas were especially able to utilize the phosphorus in rock phosphate. No attempt will be made to cite the various papers which compare superphosphate with rock phosphate, but in general they show that the availability of phosphoric acid in rock phosphate is considerably lower than that in superphosphate.

Greenhouse and field tests were conducted in this investigation for the purpose of determining the relative value of waste pond phosphate[4] as compared with superphosphate and rock phosphate.

PLAN OF EXPERIMENTS

A number of greenhouse pot experiments were conducted in which the various phosphate fertilizers and soils were used. The P_2O_5 content of the fertilizers was as follows: Superphosphate, 17.46% P_2O_5; rock phosphate (Tenn. brown rock), 33.09% P_2O_5; No. 1 waste pond phosphate, 20.92% P_2O_5; and No. 2 waste pond phosphate, 23.0% P_2O_5. The soils used were Sumter, Cecil, and Eutaw clays; Decatur clay loam; Norfolk fine sandy loam, and Hartsells very fine sandy loam. The phosphates were thoroughly mixed with the 2- to 3-inch layer of soil in each pot. Hairy vetch and orange sorghum were grown as the indicator crops. Potash and nitrogen fertilizers were used in all pots.

Field tests were conducted in terra cotta tile plots 3 feet in diameter and 1 foot

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication April 7, 1942.

[2]Associate Soil Chemist.

[3]Reference by numbers in parenthesis is to "Literature Cited", p. 829.

[4]Waste pond phosphate is generally sold under the following trade names: Colloidal Phosphates, PhosCalOids, Mineral Colloids, Cal-Phos, Collosfos, Vitaloid Phosphate, Lonfosco, and Colimephos.

in depth. The tile were sunk into the ground to a depth of 8 inches at which depth the drainage holes in the tile were even with the surface of the ground. The soil was removed and thoroughly composited before being replaced in the tile.

The various treatments were run in quadruplicate. Hairy vetch and orange sorghum were grown as the indicator crops.

RESULTS AND DISCUSSION

In the first series of greenhouse experiments, the soils used were Sumter, Cecil, and Eutaw clays; Decatur clay loam; Hartsells very fine sandy loam; and Norfolk fine sandy loam. Phosphate fertilizers from the different sources were applied at the rate of 96 pounds of P_2O_5 per acre. The results of this experiment are given in Tables 1 and 2. When superphosphate was used, a much higher yield of sorghum was produced in all cases than when either rock or waste pond phosphate were used. The yield of sorghum on calcareous Sumter clay was very high when superphosphate was applied; whereas, the application of waste pond and rock phosphate did not increase plant growth significantly. The increased yields of sorghum from the applications of superphosphate were from 2 to 23 times greater than the increased yields obtained from the use of waste

TABLE 1.—*The yields of sorghum on six Alabama soils fertilized with different kinds of phosphate.**

Soil type	Yield of sorghum in grams of dry weight (96 lbs. of P_2O_5 per acre added)				pH of soil
	No phosphate	Rock phosphate	Waste pond phosphate	Superphosphate	
Sumter clay	1.0	1.0	2.0	23.5	8.0
Eutaw clay	4.5	7.4	9.0	15.3	4.8
Cecil clay	1.5	2.5	2.5	14.5	5.5
Decatur clay loam	16.5	20.5	21.5	27.9	6.5
Hartsells fine sandy loam	6.9	5.5	4.6	11.1	5.4
Norfolk fine sandy loam	2.8	2.4	2.9	12.8	5.8

*One-gallon pots were used and nitrogen and potash were added to all pots.

TABLE 2.—*The yields of vetch on six Alabama soils fertilized with different kinds of phosphate.**

Soil type	Yield of vetch in grams of dry weight (96 lbs. of P_2O_5 per acre added)				pH of soil
	No phosphate	Rock phosphate	Wastepond phosphate	Superphosphate	
Sumter clay	0.1	0.1	0.5	7.4	8.0
Eutaw clay	5.4	7.1	7.4	9.4	4.8
Cecil clay	0.1	3.1	1.6	9.7	5.5
Decatur clay loam	6.2	7.0	6.9	9.8	6.5

*One-gallon pots were used and potash was added to all pots.

pond or rock phosphate. The increased yields of vetch from the use of superphosphate were from 2 to 18 times greater than the increases from the other phosphates used.

In the above experiments the fertilizers were compared on an equivalent P_2O_5 basis. Since a unit of P_2O_5 is cheaper in rock and waste pond phosphate than in superphosphate, another experiment was conducted in which the phosphate added to the soils was varied from 48 to 384 pounds of P_2O_5 per acre. The results show that all rates of superphosphate from 48 to 192 pounds of P_2O_5 per acre produced from 47 to 323% more sorghum on the Hartsells soils and from 180 to 1,000% more sorghum on the Cecil soil than rock phosphate or two brands of waste pound phosphate (Tables 3 and 4). On Hartsells soil 50 to 67% more vetch was produced by all rates of superphosphate than by the other phosphates. The data given in Table 4 show that 48 pounds of P_2O_5 per acre applied to Cecil clay is not enough to produce maximum yields of vetch; therefore, the increased yields over the no-phosphate treatments should be compared for all rates of P_2O_5 above the 48-pound rate. The increased yields of vetch from 96 pounds of P_2O_5 as superphosphate were 59% more than from 384 pounds of P_2O_5 as waste pond phosphate. The yields of vetch from waste pond phosphate were a little lower than those from rock phosphate and less than half of those from superphosphate.

TABLE 3.—*Yields of sorghum on Hartsells and Cecil clay fertilized with different rates and kinds of phosphate.**

Lbs. of P_2O_5 applied per acre	Sorghum yields in grams of dry weight				
	No phosphate	Rock phosphate	Waste pond phosphate		Super-phosphate
			No. 1 source	No. 2 source	
	Hartsells fine sandy loam				
0	17.5	—	—	—	—
48	—	26.0	16.0	20.0	30.0
96	—	21.5	19.5	22.0	41.0
144	—	20.0	21.0	20.3	44.5
192	—	20.0	20.5	19.0	53.5
240	—	23.5	26.0	24.5	—
288	—	21.5	20.0	20.0	—
384	—	20.0	19.5	19.5	—
	Cecil clay				
0	0.3	—	—	—	—
48	—	0.5	0.4	0.5	5.6
96	—	0.4	0.6	0.4	15.5
144	—	0.6	0.9	0.5	13.7
192	—	0.9	1.2	0.9	21.6
240	—	0.9	1.9	1.1	—
288	—	1.7	0.8	1.0	—
384	—	2.2	0.9	0.8	—

*Two-gallon pots were used and nitrogen and potash were added to all pots.

TABLE 4.—*Yields of vetch on Hartsells and Cecil soils fertilized with different rates and kinds of phosphate.**

Lbs. of P_2O_5 applied per acre	Vetch yields in gms. dry weight				
	No phosphate	Rock phosphate	Waste pond phosphate		Super-phosphate
			No. 1 source	No. 2 source	
		Hartsells Fine Sandy Loam			
0	12.3	—	—	—	—
48	—	11.2	13.0	13.3	18.5
96	—	12.5	13.0	12.3	19.0
144	—	12.5	11.3	12.7	18.8
192	—	15.5	12.1	13.0	18.3
240	—	16.3	12.7	12.7	—
288	—	15.3	14.0	14.3	—
384	—	12.5	13.5	14.0	—
		Cecil Clay			
0	0.6	—	—	—	—
48	—	1.4	0.8	0.8	4.9
96	—	1.4	1.1	0.4	10.5
144	—	4.4	2.1	2.5	8.5
192	—	4.7	3.5	2.4	8.4
240	—	4.4	3.3	3.4	—
288	—	5.7	5.0	3.4	—
384	—	6.8	4.2	2.8	—

*Two-gallon pots were used and potash was added to all pots.

The average increased yields of various crops for a 10-year period from superphosphate, rock phosphate, and waste pond phosphate are given in Table 5. These results were obtained from experiments located on several of the Agricultural substations and experimental fields in the state. Superphosphate increased the yields of cotton approximately 2 to 4 times and the yields of winter legumes about 2 to 6 times as much as did waste pond phosphate. Since these soils are relatively high in available phosphorus, corn responded very little to phosphate fertilization; however, superphosphate did outyield the more insoluble phosphates by about 2 or 3 bushels per acre.

One year's average results from quadruplicate tile plots on Cecil and Decatur clays showed that superphosphate greatly surpassed waste pond and rock phosphate in the production of vetch and sorghum (Table 6). Even though the rate per acre was doubled for the latter two fertilizers, superphosphate outyielded them by 24 to 906%. Since these results represent only one year of experimentation, they cannot be considered conclusive; however, they do show the same trend as those obtained from other experiments.

The same general results have been obtained from all tests in greenhouse and field experiments. On all soils that gave large crop responses from the phosphate fertilization, superphosphate gave much greater increases in yields than did rock or waste pond phosphate. This fact still held true even though the rate of the latter two

TABLE 5.—*Average increased or decreased yields of different crops from superphosphate, waste pond, and rock phosphate, 1930–1941.*

Kind of phosphate used*	Prattville Experiment Field			Wiregrass Experiment Substation			Tennessee Valley Experiment Substation			Monroeville Experiment Field	
	Seed cotton, lbs.	Corn, bu.	Vetch, lbs.	Seed cotton, lbs.	Corn, bu.	Austrian peas, lbs.	Seed cotton, lbs.	Corn, bu.	Vetch, lbs.	Cotton, lbs.	Corn, bu.
Two-year Rotation of Cotton and Corn With Legumes											
16% superphosphate	110	5.6	5,350	156	3.7	3,037	448	6.9	7,539	—	—
Rock phosphate	18	3.2	2,098	−16	−1.1	600	180	4.2	3,663	—	—
Rock phosphate†	9	2.7	2,556	−33	−1.0	820	334	7.1	5,381	—	—
Waste pond phosphate	−6	2.6	2,578	−45	−2.6	268	194	3.4	2,773	—	—
Two-year Rotation of Cotton and Corn											
16% superphosphate	—	—	—	89	1.7	—	470	5.4	—	268	1.7
Rock phosphate	—	—	—	−2	1.1	—	245	2.9	—	74	−0.3
Rock phosphate†	—	—	—	22	1.0	—	369	5.5	—	108	1.1
Waste pond phosphate	—	—	—	47	1.7	—	239	3.3	—	64	0.0

*Phosphate used at the rate of 300 lbs. of 16% superphosphate per acre or its equivalent.
†Same number of pounds of rock phosphate as superphosphate.

TABLE 6.—*Increased yields in pounds of green weight per acre of vetch and sorghum from experimental plots fertilized with different kinds of phosphate.*

Treatment	Cecil Clay		Decatur Clay	
	Vetch	Sorghum	Vetch	Sorghum
Superphosphate*	11,883	13,940	10,646	9,316
Waste pond phosphate*	4,311	4,893	1,803	2,753
Waste pond phosphate†	4,811	9,199	4,299	3,693
Rock phosphate*	4,819	9,859	5,100	4,903
Rock phosphate†	7,463	10,312	8,530	5,927

*36 lbs. P_2O_5 per acre for each crop.
†72 lbs. P_2O_5 per acre for each crop.

was doubled in the field or increased eight times in the greenhouse. Soils which responded less to phosphate fertilization did not show as great a difference between superphosphate and rock or waste pond phosphates as did the more responsive soils; however, the latter two phosphates produced decidedly less plant growth. This probably was due to the fact that the less responsive soils contained large amounts of available phosphorus or enough to produce almost maximum plant growth. Even in these cases, the more insoluble phosphates did not supply the small additional amount of available phosphorus necessary for maximum plant growth.

Waste pond and rock phosphates appear to have about the same ability to supply plants with phosphorus. There were no significant differences in the yields of vetch or sorghum from these phosphates in the greenhouse experiments. When they were used on Sumter clay (a calcareous soil), they did not increase the yields of vetch or sorghum significantly, thus indicating that the more insoluble phosphate fertilizers are of little value when used on alkaline soils. High rates of application of waste pond or rock phosphate did not increase significantly the yields of vetch or sorghum over the low rates of these fertilizers. The 10-year average yields from these two fertilizers on field plots are about the same for cotton, corn, vetch, and Austrian peas. Therefore, it appears that rock and waste pond phosphates are about equal in their ability to supply phosphorus for plant growth.

SUMMARY AND CONCLUSIONS

A number of greenhouse and field experiments were carried out to determine the relative availability of phosphorus in superphosphate, waste pond, and rock phosphates. Sumter, Eutaw, and Cecil clays; Hartsells very fine sandy loam; Norfolk fine sandy loam; and Decatur clay loam were used in the greenhouse studies. The field experiments were conducted on Decatur clay and clay loam, Cecil clay, Hartsells very fine sandy loam, and Norfolk fine sandy loam. The following general conclusions were drawn from these experiments:

1. The results from greenhouse pot tests and field experiments indicate that superphosphate is far superior to waste pond or rock phosphate as a source of phosphorus for the growth of cotton, sorghum, hairy vetch, and Austrian peas.

2. Neither rock nor waste pond phosphate increased the growth of vetch or sorghum significantly on Sumter clay (a calcareous soil), while superphosphate greatly increased the growth of these plants on this soil.
3. Waste pond and rock phosphate appear to be equal in their ability to supply phosphorus for plant growth.
4. As the rate of application of waste pond or rock phosphate was increased from 48 to 384 pounds of P_2O_5 per acre, there was very little, if any, increase in the crop yields.

LITERATURE CITED

1. Fraps, G. S. Availability of the phosphoric acid of finely divided rock phosphate. Tex. Agr. Exp. Sta. Bul. 509. 1935.
2. Hartwell, Burt I., and Damon, S. C. The degree of response of different crops to various phosphate carriers. R. I. Agr. Exp. Sta. Bul. 209. 1927.
3. McCool, M. H. Fertilizer value of colloidal phosphate. Contribution Boyce Thompson Inst., *10*:257–266. 1939.

RUNOFF, PERCOLATE, AND LEACHING LOSSES FROM SOME ILLINOIS SOILS[1]

R. S. STAUFFER[2]

IN a previous paper,[3] an installation was described in which the disposition of natural precipitation by some Illinois soils is being studied by means of erosion-type lysimeters. Data on runoff and percolation from July 11, 1935, when the experiment was started, to December 31, 1936, were included in that paper. The percolate has been analyzed for nitrogen, calcium, magnesium, potassium, sodium, sulfur, silica, and sesquioxides since October 1, 1937. It is the purpose of this paper to include some further data on the runoff and percolate from these soils and to give the results of the chemical analyses for approximately 3 years and 8 months.[4]

Eight extensively developed soil types were originally included in this study. In June 1940, one of these soils, LaRose silt loam, was replaced with a different type, Saybrook silt loam, and the Elliott silt loam was replaced with other cylinders of the same type. Lysimeter samples of these soils, taken in triplicate without disturbing the structure, were installed so that the runoff and percolate are caught separately. The soils have been kept fallow. A slope of approximately 1.4% has been maintained on all lysimeters.

DESCRIPTION OF THE SOILS

The soils being studied are described in various Illinois county soil reports, thus obviating the need for full descriptions here. They all belong to the prairie group but differ in stage of development and in origin. Osceola occurs on glacial outwash plains and has a well-developed subsoil. Tama and Muscatine are both loess-derived soils, the former on slopes of about 3.5% to 7% and the latter on slopes of about 0.5% to 3.5%. Edina and Cowden occur in regions where the loess is intermediate in depth and rests on Illinoian till, while the LaRose, Saybrook, Elliott, and Cisne all occur in shallow loess regions. LaRose and Saybrook are underlain by permeable till, Elliott by slowly permeable Wisconsin till, and Cisne by Illinoian till. The data indicate the relative permeability of these soils to water.

RESULTS

The runoff and percolation data are given in Table 1. These data are for the period of June 11, 1935, to December 31, 1935, and then by calendar years through 1941. The precipitation for the corresponding periods is also given.

[1]Contribution from the Division of Soil Physics, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director of the Experiment Station. Received for publication April 13, 1942.

[2]Assistant Professor of Soil Physics.

[3]STAUFFER, R. S., and SMITH, R. S. Variation in soils with respect to the disposition of natural precipitation. Jour. Amer. Soc. Agron., 29:917–923. 1937.

[4]The chemical analyses were made under the direction of E. E. DeTurk, Head of the Division of Soil Fertility, Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill.

The results of the chemical analyses and the amount of percolate in inches from each soil are given in Tables 2 and 3. The first analyses were made on the percolate which was collected over a period of approximately 5 months. The second analyses cover a period of 1 year with the exception of those for Osceola, Cowden, and Cisne, which cover a period of 17 months because there was not enough percolate during the first 5-month period from these three soils for analysis. The third analyses cover a period of 1 year and the fourth a period of 15 months. The last period was extended to 15 months so there would be enough percolate from all lysimeters for analysis.

TABLE 1.—*Runoff and percolate from lysimeters of nine Illinois soils expressed as percentages of total precipitation, averages of triplicates.*

	Osceola	Tama	Muscatine	Edina	Cowden	LaRose	Saybrook	Elliott A	Elliott B	Cisne	Precipitation, in.
					June 11, 1935, to Dec. 31, 1935						
Runoff...	21.5	8.6	9.4	10.4	14.0	19.6	—	7.8	—	14.5	—
Percolate	7.5	31.6	37.9	30.6	7.0	22.9	—	27.8	—	4.3	19.99
					Jan. 1, 1936, to Dec. 31, 1936						
Runoff	33.7	23.3	23.2	25.0	36.6	31.2	—	26.1	—	24.8	—
Percolate	2.2	15.7	22.2	14.5	1.1	7.3	—	13.0	—	4.4	35.81
					Jan. 1, 1937, to Dec. 31, 1937						
Runoff	34.3	19.4	21.6	23.9	40.1	23.5	—	16.4	—	37.3	—
Percolate	13.1	24.7	30.8	21.8	7.4	21.2	—	30.0	—	7.4	37.42
					Jan. 1, 1938, to Dec. 31, 1938						
Runoff	41.8	29.4	26.2	31.7	43.1	36.4	—	26.2	—	38.4	—
Percolate	2.7	13.4	21.6	9.9	2.7	8.3	—	16.1	—	2.6	41.25
					Jan. 1, 1939, to Dec. 31, 1939						
Runoff	42.2	34.1	30.7	36.9	41.9	33.7	—	25.8	—	40.3	—
Percolate	1.1	8.2	12.7	6.6	0.7	6.1	—	11.5	—	0.6	40.04
					Jan. 1, 1940, to Dec. 31, 1940						
Runoff	21.9	17.2	11.9	20.0	25.4	19.1*	2.1†	7.4*	5.9†	22.8	—
Percolate	2.2	3.1	10.8	3.9	1.0	0.5	30.1	13.3	16.3	0.4	27.88
					Jan. 1, 1941, to Dec. 31, 1941						
Runoff	35.1	28.2	24.1	32.7	37.6	—	16.4	—	22.5	35.0	—
Percolate	2.5	10.9	23.0	6.9	2.3	—	34.6	—	21.0	1.0	43.94

*Removed May 21, 1940. Precipitation January 1, 1940, to May 21, 1940, was 9.80 inches.
†Installed July 1, 1940. Precipitation July 1, 1940, to December 31, 1940, was 12.16 inches.

Table 3 gives the total amount of the constituents removed in the percolate during the period from October 1, 1937, to May 31, 1941. Table 4 is included to show the variation in losses of nitrogen, calcium, and water by percolation from the triplicate lysimeters of each soil.

DISCUSSION AND CONCLUSIONS

The data in Table 1 show that the soils included in this study vary considerably in permeability to water. This is in accordance with

TABLE 2.—*Pounds per acre of various constituents removed in percolate from nine Illinois soils and percolate in inches.*

Soil type	N	Ca	Mg	K	Na	S	SiO_2	R_2O_3*	Percolate, in.
				Oct. 1, 1937, to Feb. 28, 1938					
Osceola†	—	—	—	—	—	—	—	—	—
Tama	50.8	49.7	26.5	0.4	6.2	2.1	6.2	—	3.427
Muscatine	30.5	42.8	24.5	0.9	7.4	12.9	7.3	—	4.531
Edina	26.3	25.1	15.1	0.2	9.9	4.3	3.1	—	2.268
Cowden†	—	—	—	—	—	—	—	—	—
LaRose	26.5	35.0	18.0	0.4	2.8	4.5	2.2	—	2.226
Elliott	53.0	76.8	41.6	0.6	5.3	15.8	6.8	—	3.646
Cisne†	—	—	—	—	—	—	—	—	—
				Mar. 1, 1938, to Feb. 28, 1939					
Osceola‡	5.7	6.7	6.2	0.5	3.4	2.8	1.9	0.2	1.100
Tama	48.4	47.4	26.7	1.1	5.1	3.8	8.0	1.0	4.049
Muscatine	96.1	111.8	64.7	2.7	10.9	20.2	13.0	2.2	8.353
Edina	31.8	35.6	21.4	1.0	11.9	3.7	4.7	0.4	3.077
Cowden‡	6.2	12.9	4.7	0.5	4.8	2.9	0.9	0.4	1.139
LaRose	23.8	30.4	15.1	0.8	1.8	3.6	1.9	0.2	2.059
Elliott	73.3	115.1	61.3	2.0	12.7	22.7	9.8	1.7	5.701
Cisne‡	8.2	7.5	5.1	0.4	19.6	1.1	2.3	0.3	1.093
				Mar. 1, 1939, to Feb. 29, 1940					
Osceola	2.7	2.5	2.0	0.3	1.5	0.8	0.3	0.2	0.445
Tama	32.6	32.7	16.2	0.5	3.4	2.4	3.5	1.2	2.217
Muscatine	49.9	44.9	25.4	0.2	5.1	6.8	5.2	2.0	2.840
Edina	23.5	26.3	13.6	0.2	7.9	3.3	3.2	1.0	1.939
Cowden	1.7	3.6	1.1	0.2	1.3	0.6	0.4	0.3	0.285
LaRose	20.8	29.2	14.3	0.3	2.4	3.1	1.9	1.4	1.881
Elliott	53.1	66.6	36.1	0.5	9.0	14.4	3.7	2.5	3.246
Cisne	1.0	1.6	0.9	0.5	4.5	0.3	0.4	0.1	0.250
				Mar. 1, 1940, to May 31, 1941					
Osceola	20.5	19.2	13.1	1.0	6.4	3.2	2.0	0.6	1.541
Tama	65.8	62.4	32.7	0.5	6.3	4.4	4.4	1.5	3.257
Muscatine	104.4	111.9	60.1	1.2	10.2	12.8	9.0	2.0	7.276
Edina	46.6	46.9	24.4	1.3	13.8	4.5	4.3	1.3	2.931
Cowden	14.7	23.5	7.2	1.6	7.2	1.8	0.9	0.6	1.086
LaRose§	0.7	0.8	0.6	0.1	0.2	0.2	0.1	0.1	0.044
Saybrook‖	91.1	142.8	65.0	1.2	10.3	24.5	7.8	2.2	8.230
Elliott§	23.2	29.3	17.2	0.6	3.3	4.7	2.1	0.4	1.301
Elliott‖	17.2	67.4	35.7	1.0	8.7	42.3	4.6	1.3	4.832
Cisne	5.0	2.4	1.9	1.5	14.2	0.4	0.5	0.2	0.423

*Iron and aluminum not determined in the first analysis.
†Not enough percolate for analysis.
‡Covers a period of 17 months.
§For the period March 1, 1940, to May 31, 1940. These soils were removed June 1, 1940.
‖For the period July 1, 1940, to May 31, 1941.

observations in the field and also with other infiltration studies. During the entire period of 6 years and 7 months for which results are given, there were 246.33 inches of precipitation. Muscatine lost 55.3 inches of this water by runoff, while Cowden lost 89.1 inches. The water that drained through the soil during this period amounted to 54.2 inches from Muscatine and only 7.2 inches from Cowden.

TABLE 3.—*Total pounds per acre of constituents removed in drainage water from nine Illinois soils and of percolate in inches for 3 years and 8 months.*

Soil type	N	Ca	Mg	K	Na	S	SiO_2	R_2O_3	Percolate, in.
Osceola	28.9	28.4	21.3	1.8	11.3	6.8	4.2	1.0	3.086
Tama	197.6	192.2	102.1	2.5	21.0	12.7	22.1	3.7	12.950
Muscatine	280.9	311.4	175.0	5.0	33.6	52.7	34.5	6.2	23.000
Edina	128.2	139.9	74.5	2.7	45.0	15.8	15.3	2.7	10.216
Cowden	22.6	40.0	13.0	2.3	13.3	5.3	2.2	1.3	2.509
LaRose*	71.8	95.4	48.0	1.6	7.2	11.4	6.1	1.7	6.165
Saybrook†	91.1	142.8	65.0	1.2	10.3	24.5	7.8	2.2	8.230
Elliott*	202.6	287.8	156.2	3.7	30.3	57.6	22.4	4.6	12.594
Elliott†	17.2	67.4	35.7	1.0	8.7	42.3	4.6	1.3	4.832
Cisne	14.2	11.5	7.9	2.4	38.3	1.8	3.2	0.6	1.767

*For a period of 2 years and 8 months.
†For a period of 11 months.

The results of the chemical analyses show wide variation also in the amounts of plant nutrients removed from the different soils by leaching. For example, during the entire 3 years and 8 months covered by this phase of the study, Muscatine lost 311.4 pounds of calcium per acre, or approximately 27 times as much as Cisne which lost only 11.5 pounds. These differences are probably due to some extent to the fact that Cisne contains a smaller amount of calcium than Muscatine, but to a greater extent to the fact that the amount of water draining through Cisne is also much smaller.

The variation in drainage losses of different constituents from year to year is also of interest. The losses seem to depend largely on

TABLE 4.—*Variation in the loss of nitrogen and calcium in pounds per acre in the percolate and of the percolate in surface inches for triplicate lysimeters for 3 years and 8 months.*

Soil type	N	Ca	Percolate, in.	Soil type	N	Ca	Percolate, in.
	17.1	19.4	2.62		65.0	91.9	5.61
Osceola	36.1	36.4	3.63	LaRose*	80.0	99.5	7.68
	33.1	29.0	2.98		70.3	94.6	5.32
	209.1	196.3	14.30		92.5	152.4	8.04
Tama	187.5	182.4	12.49	Saybrook†	104.4	167.2	8.65
	196.3	197.6	12.04		76.5	108.8	8.01
	253.3	242.8	22.71		240.6	335.2	15.51
Muscatine	284.9	391.1	22.94	Elliott*	163.4	281.6	13.98
	304.5	302.3	22.72		203.8	246.7	12.11
	143.3	137.7	10.98		32.6	93.1	6.22
Edina	113.8	107.1	8.15	Elliott†	8.2	54.9	4.19
	127.6	157.0	11.27		11.1	54.5	4.08
	18.9	32.7	2.47		19.6	17.4	2.06
Cowden	29.7	54.5	2.88	Cisne	12.1	9.8	1.56
	19.0	32.9	2.25		11.0	7.2	1.66

*For 2 years and 8 months.
†For 11 months.

the amount of drainage which in turn depends to a considerable extent upon the amount of precipitation. However, the amount of drainage is influenced by factors other than total precipitation, such as distribution and intensity of the precipitation. These factors are not discussed in this paper since it is proposed to present them at some future time.

At present chemical analyses are being made every 3 months, but this work has not progressed far enough to draw any conclusions as to the seasonal drainage losses.

Different methods, none of which are entirely satisfactory, have been used by various investigators to determine the amount of certain constituents removed from soils by leaching. It is realized that the results reported in this paper are not likely to be exactly the same as the losses which occur from the same soils under natural conditions. However, since the natural structure of these soils was not altered when the lysimeter samples were taken and since they are set up so that runoff can occur, the results should approach natural conditions more closely than some that have been reported. The drainage losses of nutrients found in this study are smaller than some that have been reported. For example, the drainage losses from the Cornell lysimeters,[5] which are probably the most frequently quoted of any in the United States, were higher for all constituents reported, except nitrogen, than those even from the most productive soils reported in this paper. However, direct comparisons should not be made, for the Cornell lysimeters are the filled-in type with no provision for runoff, and also their bare lysimeters received applications of lime and manure at regular intervals. Furthermore, in filled-in lysimeters new surfaces of soil are undoubtedly exposed to the solvent action of water which might cause an increase in the amount of various constituents removed. The kind of installation used in this investigation also permits the study at the same time of a number of soils having widely different physical and chemical properties. This is desirable since some idea of soil variation can thus be obtained. Too frequently results secured on one soil have been applied to other soils having entirely different properties and environments.

The results given in Table 3 show that much larger amounts of plant nutrients are lost from the more productive soils than from the less productive ones. This would serve to emphasize the importance of utilizing soil conservation practices on the better soils. The results also show that the loss of plant nutrients depends largely on the amount of water passing through the soil. This may be worth considering when so much effort is being made to reduce the amount of runoff from soils. In many cases this means that more water is entering the soil than previously and that loss of nutrients by leaching may be considerably increased. This may be particularly true if mechanical means rather than vegetative cover is depended upon to control the runoff. If a cover crop is kept on the soil, both leaching losses and loss of water by percolation will be held to a minimum. It re-

[5]Lyon, T. L., Bizzell, J. A., Wilson, B. D., and Leland, E. W. Lysimeter Experiments. III. Records for tanks 3 to 12 during the years 1910 to 1924, inclusive. Cornell Univ. Agr. Exp. Sta. Mem. 134. 1930.

emphasizes the importance of controlling erosion insofar as possible by vegetation, and of keeping a cover crop on the soil as much of the time as possible even though it may be necessary to use supplementary mechanical means to control erosion. In humid regions the use of mulches of such materials as straw by increasing the infiltration capacity of the soil may accelerate the loss of nutrients by leaching.

As stated previously, Table 4 is included in this paper to show the variation in triplicate determinations on the same soil for nitrogen, calcium, and water by percolation. The variation for other constituents is of approximately the same order.

SUMMARY

In June 1935, studies on runoff and percolation were started on eight extensively developed Illinois prairie soils. The erosion-type lysimeters are used in this study. In June 1940, LaRose silt loam was replaced with Saybrook silt loam and the Elliott silt loam was replaced by other cylinders of the same soil. These soils have been kept bare and have not been cultivated. Any plant growth is removed with as little disturbance of the surface as possible. No materials have been added to the soils.

For the period of June 11, 1935, to December 31, 1941, the runoff from Muscatine averaged 22.4% of the precipitation, while that from Cowden amounted to 36.2%. The percolate from Muscatine averaged 22.7% of the precipitation and that from Cowden 3.6%.

There was wide variation also in the amounts of plant nutrients removed from the soils by leaching. For example, Muscatine lost 311.4 pounds of calcium per acre in 3 years and 8 months, or a little more than 27 times as much as Cowden which lost 11.5 pounds in the same time.

INHERITANCE AND LINKAGE OF FACTORS FOR RESISTANCE TO TWO PHYSIOLOGIC RACES OF *CERCOSPORA ORYZAE* IN RICE[1]

T. C. RYKER AND S. J. P. CHILTON[2]

BLUE ROSE rice which is grown on about 49% of the rice acreage in the southern states is very susceptible to *Cercospora oryzae*. A selection from Blue Rose, named Blue Rose 41, which is resistant to the fungus under field conditions, has been obtained and at present is being increased for distribution. A strain of the fungus has been found, however, to which this selection is susceptible and to which Blue Rose is somewhat resistant (2, 4).[3] The two strains have been named races 1 and 2.

Ryker and Jodon (5), working with race 1, reported that resistance to *Cercospora oryzae* was conditioned by a single dominant factor. When attempts were made to combine the resistance of Blue Rose 41 to race 1 and the moderate resistance of Blue Rose to race 2, it was found that linkage existed between resistance to one strain of the fungus and susceptibility to the other. It is the purpose of this paper to give the results of this study. A brief summary has already been published (3).

MATERIALS AND METHODS

Crosses were made between Blue Rose and Blue Rose 41, using the hot water technic of emasculation (1) prior to pollination. The F_1 plants were grown in crocks at Baton Rouge, La. The F_2 and F_3 populations were grown both in crocks in the greenhouse at Baton Rouge and in space-planted rows in the field at Crowley, La. None of the plants was bagged as relatively little cross-pollination occurs in rice.

The plants were inoculated either by spraying them with a spore suspension and holding in a moist chamber for 48 hours, after which they were placed outdoors, or by spraying the plants outdoors between sundown and dark. After the reaction to one strain of the fungus was obtained, the plants were tagged, returned to the greenhouse, and all leaves removed. Infection does not spread in the greenhouse, and when new leaves formed, the plants were inoculated with the other strain of the fungus without fear of contamination from the previous inoculation.

The plants in the field at Crowley were inoculated early in the season before an appreciable amount of natural infection occurred.

EXPERIMENT RESULTS

The F_1 plants were inoculated with race 2 to which the parent Blue Rose is moderately resistant and all were found to be identical with Blue Rose in regard to their reaction to this race of the fungus. These plants were not inoculated with race 1, but when exposed to natural infection none showed the susceptible reaction of Blue Rose.

[1]Contribution of the Louisiana Agricultural Experiment Station, Baton Rouge, La. Received for publication April 27, 1942.

[2]Assistant Plant Pathologists.

[3]Figures in parenthesis refer to "Literature Cited", p. 840.

TABLE 1.—*Reaction of F_2 plants from the cross Blue Rose × Blue Rose 41 to race 1 of Cercospora oryzae in 1939.*

Cross	Where tested	Number of F_2 plants			
		Resistant	Susceptible	Total	Chi²* (3:1)
Blue Rose × Blue Rose 41	Baton Rouge	158	42	200	1.71
Blue Rose 41 × Blue Rose	Baton Rouge	109	29	138	1.17
Blue Rose 41 × Blue Rose	Crowley	49	15	64	0.08
Blue Rose 41 × Blue Rose	Baton Rouge	239	82	321	0.05
Blue Rose 41 × Blue Rose	Crowley	115	31	146	1.11
Total		670	199	869	2.04

*Chi² = 3.841 with P of .05.

The F_2 populations were grown and tested for disease reaction in 1939, 1940, and 1941. In 1939 only the reaction to race 1 was determined. The data shown in Table 1 confirm previous results (2) that resistance to race 1 is controlled by a single dominant factor.

In 1940 and 1941 the reaction of F_2 populations to both races of the fungus was determined. The results are given in Table 2 and again show that resistance to race 1 is due to a single dominant factor. With respect to race 2, segregation ratios indicate a single dominant factor for resistance, but the agreement with the theoretical 3:1 ratio is poor as a large deficiency of susceptible plants occurred.

Resistant and susceptible plants are easily classified when inoculated with race 1 as the difference is clear cut (Fig. 1). The incubation

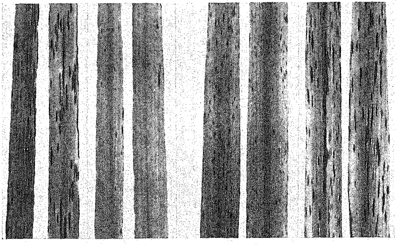


FIG. 1.—Reaction of F_2 segregates of the cross Blue Rose × Blue Rose 41 inoculated with races 1 and 2 of *Cercospora oryzae*. Left to right in groups of two leaves, susceptible to race 1; resistant to race 1; moderately resistant to race 2; susceptible to race 2.

period of race 1 on resistant plants is approximately 10 days longer than on susceptible plants and the spots are small. It is more difficult to determine the difference between resistant and susceptible plants inoculated with race 2, as the incubation period on a resistant plant is only 2 to 3 days longer than on susceptible plants, and the spots are one-half to two-thirds the size of those on a susceptible plant (Fig. 1). This accounts for the discrepancy in results when supposedly susceptible plants in the F_2 populations were inoculated with race 2.

TABLE 2.—*Segregation for resistance to races 1 and 2 of Cercospora oryzae in F_2 populations artificially inoculated in 1940 and 1941.*

Cross	Year tested	No. of plants tested	Inoculated with race 1*			Inoculated with race 2		
			Resistant	Susceptible	Chi² (3:1)	Resistant	Susceptible	Chi² (3:1)
Blue Rose 41 × Blue Rose...	1940	164	126	38	0.29	132	32	2.63
Blue Rose 41 × Blue Rose...	1940	309	234	75	0.09	273	36	29.37
Blue Rose × Blue Rose 41	1940	130	89	41	2.96	111	19	7.48
Blue Rose 41 × Blue Rose...	1940	249	193	56	0.85	213	36	14.76
Blue Rose 41 × Blue Rose...	1941	160	111	49	2.70	126	34	1.20
Blue Rose 41 × Blue Rose...	1941	275	196	79	2.04	213	62	0.88
Total.....		1,287	949	338	1.09	1,068	219	43.75

*Chi² = 3.841 with P of .05.

In 1940 the F_3 populations of 41 F_2 plants resistant to race 1 and 14 F_2 plants susceptible to race 1 were grown in rod rows in the field at Crowley and inoculated with race 2. Based on the reaction of these F_3 families to race 2, 28 of the 41 F_2 plants resistant to race 1 were heterozygous for resistance to race 2 and 13 were homozygous for susceptibility. Of the 14 F_2 plants susceptible to race 1, 13 were homozygous for resistance to race 2 and 1 was susceptible. The above results indicated a linkage between the genes for resistance to race 1 and susceptibility to race 2, as some plants homozygous for resistance to race 2 should have occurred among the 41 plants resistant to race 1 and more than 1 plant homozygous for susceptibility to race 2 should have occurred among the 14 plants susceptible to race 1.

The F_3 populations of 110 F_2 plants of which the reaction to one or both races was known were then grown in pots at Baton Rouge and tested with both races of the fungus. The results are given in Table 3. It may be seen from the data that very close linkage existed between resistance to one race and susceptibility to the other as only 1 plant in 110 was obtained which was homozygous with respect to its

reaction to one race and heterozygous with respect to the other, and no plants were obtained which were homozygous with respect to either resistance or susceptibility to both races.

TABLE 3.—*Reaction of F_3 plants from the cross Blue Rose×Blue Rose 41 to races 1 and 2 of Cercospora oryzae.*

Reaction of F_2 plants to races 1 and 2	No. of F_2 plants	No. of F_3 plants tested	Reaction of F_3 plants*					
			Race 1			Race 2		
			Resistant	Susceptible	Chi²† (3:1)	Resistant	Susceptible	Chi² (3:1)
Susceptible to race 1	17	386	2	384	—	380	6	—
Resistant to race 1..	9	230	230	0	—	14	216	—
Resistant to race 1..	8	213	157	56	0.189	159	54	0.014
Resistant to race 1, Susceptible to race 2...............	18	398	393	5	—	12	386	—
Resistant to races 1	57	1,414	1,089	325	3.064	1,071	343	0.416
and 2...........	1	27	25	2	—	12	15	—

*The F_4 generation of 80 of the plants which did not fit into the expected were grown and tested with races 1 and 2. Of these plants 72 were misclassifications, 3 were undetermined, and in 5 linkage was apparently broken.

†$Chi^2 = 3.841$ with P of .05.

The data also show that resistance to race 2 is due to a single dominant factor, segregation of heterozygous F_2 plants giving a ratio of approximately 3 resistant to 1 susceptible in a total of 1,627 plants ($Chi^2 = .265$).

Seeds were obtained from 80 F_3 plants which were classed as susceptible to both races or which did not fit the expected ratios. The F_4 plants were grown and tested for their reaction to the two races of the fungus. It was found that 72 of these 80 plants were misclassifications, 3 were undetermined; and of the 5 possible cross-overs obtained, 3 appeared to be the double recessive and 2 the double dominant. The occurrence of the two homozygous resistant plants gives hope of obtaining a variety resistant to both races of the fungus. The misclassifications were probably due to the difficulty of always differentiating between resistant and susceptible reactions to the fungus in individual plants.

SUMMARY

1. The resistance of Blue Rose 41 to race 1 of *Cercospora oryzae* is conditioned by a single dominant factor. The moderate resistance of Blue Rose to race 2 is also due to another single dominant factor.

2. Close linkage exists between resistance to one race of the fungus and susceptibility to the other. In crosses between Blue Rose and Blue Rose 41, a very few plants have been obtained in which the linkage seems to have been broken.

LITERATURE CITED

1. JODON, N. E. Experiments on artificial hybridization of rice. Jour. Amer. Soc. Agron., 30:294–305. 1938.
2. RYKER, T. C. Physiological specialization in *Cercospora oryzae*. Abstract in Phytopath., 31:21. 1940.
3. ————. Linkage in rice of two resistant factors to *Cercospora oryzae*. Abstract in Phytopath., 31:19. 1941.
4. ————. The occurrence of physiologic specialization in *Cercospora oryzae*. In press in Phytopathology.
5. ———— and JODON, N. E. Inheritance of resistance to *Cercospora oryzae* in rice. Phytopath., 30:1041–1047. 1940.

THE INFLUENCE OF CLIPPING TREATMENT AND ROLLING ON THE YIELD OF CLOVER SEED[1]

C. R. MEGEE, M. G. FRAKES, AND I. T. LARSEN[2]

AT the present time there is considerable confusion among those interested in clover seed production concerning the handling of the growing crop when it is intended for seed. Should the crop be clipped, rolled, or pastured, or should it be left entirely alone? Is it possible to clip in order that less vegetative growth may be handled at harvest time and not reduce the seed yield? If clipping is neglected during the early stages of growth, will rolling prove advantageous? Do all clovers respond alike to these treatments? What is the influence of seasonal conditions upon clovers clipped at various stages of growth?

With these questions in mind, a series of experiments were laid out in 1937 at Michigan State College. These experiments have been continued by reseeding each year on a new area. Quite naturally no two seasons have been alike and the behavior of the clovers has varied with the particular season.

MAMMOTH RED CLOVER

On the more productive land during seasons of average or greater than average rainfall, it may be most advantageous to clip mammoth red clover to facilitate harvest. If it is not likely that plant growth will become so heavy that it will not hinder harvest, nothing will be gained by clipping (Table 1). Late clipping is very hazardous and results in greatly reduced seed yields. If it is thought that the mammoth clover is making such a rank growth that harvest will be hindered and the recommended stage for clipping has passed, much of the advantage of clipping to facilitate harvest may be gained by rolling. The average yield of seed for the unclipped plots for the years 1938 to 1941, inclusive, was 3.9 bushels per acre; for the rolled plots for the same period, 3.6 bushels; and for the early clipped plots, 3.6 bushels.

Rolling must be done at the right stage or a great loss of seed will result. The proper stage to roll is just previous to or at the early bloom stage. When rolled at this stage, the blossom buds turn upward as they develop and, when harvested, the seed-bearing parts and a portion of the stems are clipped off and bunched by the mowing machine, while the bulk of the clover plant is left in the field and not handled. When mammoth clover is rolled too late, the blossoms will not turn up and will not reach a height suitable for harvest, and much of the seed crop will be lost.

The length of the period over which mammoth clover can be clipped and a satisfactory seed yield obtained varies greatly, depending largely upon the distribution of rainfall during the regrowth period. During 1938, conditions were favorable for the production of the

[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 585 N. S. Received for publication May 6, 1942.

[2]Research Professor and Graduate Assistants respectively.

second growth so that a light hay crop was harvested and seed production was not decreased. During 1939 and 1940, the rainfall was not well distributed and the vegetative growth was sparse, the seed-bearing stems and branches were scant, and the yield of the seed was greatly diminished. Since seasonal conditions cannot be anticipated, clipping early when only 3 to 4 inches of top growth is removed is much safer than clipping later.

TABLE 1.—*The influence of clipping upon the seed yield of mammoth clover.*

Treatment	Stage of growth	Bushels of seed per acre				
		1938	1939	1940	1941	Average
Not clipped.....	———	3.5	3.8	3.7	4.0	3.9
Clipped May 23.	7 in. high	4.3	3.0	3.8	3.3	3.6
Clipped June 1..	12 in. high	4.5	1.2	3.2	2.7	2.9
Clipped June 8..	15 in. high	4.0	1.0	0.0	2.1	—
Clipped June 15.	19 in. early bud	3.8	0.5	0.0	1.8	—
Clipped June 23.	23 in. late bud	0.0	0.0	0.0	0.0	—
Clipped July 1..	23 in. early bloom	0.0	0.0	0.0	0.0	—

MEDIUM RED CLOVER

The problem of eliminating excessive plant growth during harvest and threshing is much reduced for medium red or June clover as the first cutting is usually taken for hay and the second for seed. The highest yields of seed in these trials were obtained when the first crop was cut in the early bloom stage (Table 2, June 8 clipping) and before any of the heads turned brown. The seed yields declined very rapidly when the first crop was left until the heads started to turn brown (Table 2, June 23 clipping). In 1938, 1939, and 1941 the first crop did not produce as high a yield of seed as the maximum yield of the second crop.

TABLE 2.—*The influence of clipping upon the seed yield of medium red clover.*

Treatment	Stage of growth	Bushels of seed per acre				
		1938	1939	1940	1941	Average
Not clipped.....	———	1.0	1.8	3.0	2.0	1.9
Clipped May 23.	10 in. high	1.9	2.0	2.3	2.2	2.1
Clipped June 1..	14 in. early bud	2.7	2.3	3.1	2.7	2.7
Clipped June 8..	18 in. early bloom	3.3	2.9	2.9	2.9	3.0
Clipped June 15.	20 in. ¾ bloom	2.9	2.1	2.7	2.6	2.6
Clipped June 23.	20 in. ¼ brown	0.0	1.0	1.7	1.9	—
Clipped July 1..	20 in. ¾ brown	0.0	0.0	2.0	1.5	—

Yields of seed obtained from the second crop, that is when the first crop was cut at the proper time, were fairly uniform and dependable, averaging 3 bushels per acre. Yields of seed from the first crop were rather erratic, depending upon seasonal conditions. The 1938 season was unfavorable for the first crop to produce seed and the yield was

low. In 1939, conditions were about average and in 1940 the early part of the season was as favorable as the latter and the first crop produced as high a yield of seed as the second.

TABLE 3.—*The influence of clipping upon the seed yield of alsike clover.*

Treatment	Stage of growth	Bushels of seed per acre				
		1938	1939	1941	1940	Average
Not clipped.......	———	2.6	4.3	6.0	5.5	4.6
Clipped May 23...	7 in. high	1.3	0.5	3.4	1.0	1.5
Clipped June 1....	11 in. early bud	0.0	0.0	3.1	0.6	—
Clipped June 8....	13 in. ½ bloom	0.0	0.0	0.9	0.4	—
Clipped June 15...	17 in. full bloom	0.0	0.0	0.5	0.3	—
Clipped June 23...	19 in. ¼ brown	0.0	0.0	0.0	0.0	—
Clipped July 1....	19 in. ¾ brown	0.0	0.0	0.0	0.0	—

ALSIKE CLOVER

Occasionally fields of alsike clover intended for seed production become infested with weeds and clipping for weed control is sometimes practiced. Clipping at any time after the Alsike reaches a height of more than 6 inches (Table 3) resulted in a very marked decrease in seed production. Decreases in seed production from clippings made after the 6-inch stage were so great as to point out strongly that alsike intended for seed production should not be clipped at all unless the weed problem was very serious.

The Ohio Agricultural Experiment Station in its Bimonthly Bulletin for March-April 1934 reports similar results from clipping medium red, mammoth red, and alsike clover under Ohio conditions.

SUMMARY AND CONCLUSIONS

Mammoth clover seed production is not increased by clipping; however, it is possible to reduce excessive plant growth and facilitate harvesting by clipping. Early clipping did not reduce the seed production appreciably. Late clipping of mammoth clover is hazardous and the advantages with respect to the ease of harvest may be gained by rolling just previous to bloom. Late rolling may cause loss of the seed crop.

A higher and more consistent yield of seed was obtained by cutting the first crop of medium red clover for hay during the blossom stage and before the blossoms turned brown.

Alsike clover seed yields were decidedly decreased by clipping, regardless of seasonal conditions.

DISTRIBUTION OF YIELDS OF SINGLE PLANTS OF VARIETIES AND F_2 CROSSES OF BARLEY[1]

F. R. IMMER[2]

VERY little is known about the distribution of the yields of single plants of cereal crops grown in space-planted rows. Experience indicates that the correlation between the yield of single plants in segregating populations and the mean of the plant progeny rows is low. The yield of single plants appears to be determined largely by environmental factors.

If single plant yields are to be used in genetic or plant breeding studies, some knowledge of the distribution curves of such yields in varieties and crosses would appear to be of considerable interest. This study is concerned with an analysis of such single plant yields in varieties and crosses in barley.

MATERIALS AND METHODS

In 1937 four varieties of barley (Barbless, Velvet, Peatland, and Korsbyg) and four F_2 corsses (Minia × Peatland, Barbless × Peatland, Velvet × Peatland, and Velvet × Korsbyg) were grown in space-planted rows. The seed was spaced 5 inches apart in rows 1 foot apart and 18 feet long. One hundred kernels (2½ rows) were used for each variety plot. Two hundred kernels (5 rows) were used for each plot of the F_2 crosses. Two plants of a variety with black kernels were planted at the beginning and end of each row and removed before harvest. The experimental design was one of "split-plots", the four varieties and four crosses being randomized within these groups and the order of varieties vs. crosses being at random within replications. Separate analyses of variance were calculated for each group, i.e., varieties or crosses. The blocks of varieties were 10 by 18 feet and the blocks for crosses were 20 by 18 feet.

The plants were harvested individually, threshed, and the grain weight recorded in grams to an accuracy of 0.1 gram. The yields of the plants in each plot were combined into a frequency distribution with 0.5-gram intervals. From the data for each plot was calculated k_1, k_2, k_3, k_4, g_1, and g_2 (1).[3] The formulas for the k and g statistics are given below:

$$k_1 = \bar{x}$$

$$k_2 = \frac{1}{N-1} S(x-\bar{x})^2$$

$$k_3 = \frac{N}{(N-1)(N-2)} S(x-\bar{x})^3$$

$$k_4 = \frac{N}{(N-1)(N-2)(N-3)} \left\{ (N+1)\, S(x-\bar{x})^4 - \frac{3(N-1)}{N} [S(x-\bar{x})^2]^2 \right\}$$

$$g_1 = k_3/k_2{}^{3/2}$$
$$g_2 = k_4/k_2{}^2$$

[1]Paper No. 2002, Scientific Journal Series, Minnesota Agricultural Experiment Station, University Farm, St. Paul, Minn. Received for publication May 22, 1942.
[2]Professor of Agronomy and Plant Genetics.
[3]Figures in parenthesis refer to "Literature Cited", p. 850.

where $\bar{x}$ is the plot mean, x is an individual plant yield, and N is the number of plants per plot. The above formulas were converted to the form given by Fisher (1) for ease in calculation.

EXPERIMENTAL RESULTS

In Table 1 are given the values of k and g for each plot of each of the varieties of barley and the arithmetic averages.

TABLE 1.—*Values of k and g per plot of four varieties of barley calculated from the yield per plant in grams.*

Replicate No.	N	k_1	k_2	k_3	k_4	g_1	g_2
			Barbless				
1..........	72.0	7.825	22.25	97.07	251.77	0.925	0.509
2..........	94.0	8.902	17.43	18.92	−162.69	0.260	−0.536
3..........	82.0	8.852	17.70	21.89	−255.35	0.294	−0.815
4..........	75.0	6.927	10.64	11.22	− 59.16	0.323	−0.523
5..........	102.0	6.426	12.40	23.82	− 2.32	0.546	−0.015
6..........	92.0	6.754	15.35	40.36	33.93	0.671	0.144
Av.......	86.2	7.614	15.96	35.55	− 32.30	0.503	−0.206
			Velvet				
1..........	70.0	7.393	18.06	28.14	−136.56	0.367	−0.419
2..........	94.0	6.870	14.35	10.14	− 59.38	0.187	−0.288
3..........	91.0	6.618	15.65	22.14	−139.36	0.358	−0.569
4..........	91.0	6.881	15.55	40.41	64.41	0.659	0.266
5..........	88.0	6.075	9.70	10.27	− 53.71	0.340	−0.571
6..........	92.0	5.999	14.63	20.83	−112.60	0.372	−0.526
Av.......	87.7	6.639	14.66	21.99	− 72.87	0.380	−0.351
			Peatland				
1..........	88.0	10.177	16.29	5.23	1.31	0.080	0.005
2..........	82.0	7.926	19.59	37.31	−113.11	0.430	−0.295
3..........	74.0	9.477	19.48	− 3.46	−342.11	−0.040	−0.902
4..........	81.0	7.731	21.52	50.38	−446.69	0.505	−0.965
5..........	87.0	5.941	11.32	34.78	− 72.73	0.913	−0.568
6..........	83.0	5.567	11.21	31.34	105.72	0.835	0.841
Av.......	82.5	7.803	16.57	25.93	−144.60	0.454	−0.314
			Korsbyg				
1..........	60.0	6.225	14.77	31.24	− 73.93	0.550	−0.339
2..........	55.0	6.545	16.86	54.54	68.90	0.788	0.242
3..........	75.0	3.793	8.61	24.84	60.25	0.983	0.813
4..........	86.0	4.433	8.62	15.37	− 19.15	0.607	−0.258
5..........	83.0	4.001	6.70	10.14	− 9.16	0.585	−0.204
6..........	73.0	4.118	10.94	38.23	67.99	1.057	0.568
Av.......	72.0	4.852	11.08	29.06	15.82	0.762	0.137

An essentially linear relationship was found between the variety means (k_1) and average variance (k_2) of the same varieties, the higher yielding varieties having the greater variance.

In order to test for skewness of the distribution of single plant yields, k_3 was calculated. The best test of significance of k_3 (1) involves the calculation of $g_1 = k_3/k_2^{3/2}$. The sampling error of g_1, for a normal population is $\sqrt{6N(N-1)/(N-2)(N+1)(N+3)}$. The average number of plants per plot was 82. For a sample of this size the standard error of g_1 would be 0.282.

It is noted that all but one of the values of g_1 were positive, indicating that in general the distributions were skew with a piling up of individuals toward the low yield end of the distribution. Ten of 24 values of g_1 exceeded twice their standard error.

The test for kurtosis involves the calculation of k_4 and from that $g_2 = k_4/k_2^2$. The standard error of g_2 for a normal population (1) will be $\sqrt{24N(N-1)^2/(N-3)(N-2)(N+3)(N+5)}$. Taking an average of 82, the standard error would be 0.526.

The values of g_2 varied greatly, but none deviated from zero by as much as twice the standard error. Three of the four varietal averages of g_2 were negative, indicating a slight tendency for the curves to be flat-topped. If we take $s^2_{g_2} \div \sqrt{6}$ with an average N of 82 as a rough standard error of these means, we obtain 0.215. None of the varietal averages of g_2 is significantly different from zero.

In Table 2 is given the mean squares from an analysis of variance of the k and g statistics presented in Table 1. The analyses of variance were calculated from the nonweighted plot values of k and g, i.e., each plot was given equal weight without regard to the number of plants per plot. It would appear desirable in this test to place equal emphasis on each plot.

TABLE 2.—*Mean square of k and g calculated from the varieties in Table 1.*

Variation due to	D.F.	k_1	k_2	k_3	k_4	g_1	g_2
Blocks.....	5	3.874†	32.59*	309.28	22,113	0.063	0.243
Varieties....	3	10.934†	36.19*	196.86	27,658	0.165	0.297
Error......	15	0.809	9.20	502.59	20,676	0.075	0.265

*Exceeds the 5% point.
†Exceeds the 1% point.

The differences in yield between the varieties were highly significant. The differences in variance (k_2) between the varieties exceeded the 5% point but did not reach the 1% point. The variation between blocks was significant for both k_1 and k_2, being highly significant in the case of the former. Neither blocks nor varieties differed significantly in skewness or kurtosis as measured by g_1 and g_2.

In Table 3 is given the values of k and g for each plot of each of the four F_2 crosses and the arithmetic means for each variety.

The essentially linear relationship between means and variances of the varieties did not hold for the F_2 crosses. The two highest yielding crosses, Minia × Peatland and Barbless × Peatland, had the lowest and highest variability, respectively, as measured by the variance (k_2), between yields of single plants within plots.

TABLE 3.—*Values of k and g per plot of four F_2 crosses of barley calculated from the yield per plant in grams.*

Replicate No.	N	k_1	k_2	k_3	k_4	g_1	g_2
			Minia × Peatland, F_2				
1	160.0	9.606	18.31	41.91	30.50	0.535	0.091
2	169.0	8.099	18.97	58.37	40.59	0.706	0.113
3	167.0	9.709	19.31	24.56	−188.09	0.289	−0.504
4	187.0	7.339	10.08	12.68	− 42.29	0.396	−0.416
5	187.0	7.772	15.09	41.90	227.59	0.715	0.999
6	196.0	8.159	13.78	21.34	− 21.71	0.417	−0.114
Av.	177.7	8.447	15.92	33.46	7.77	0.510	0.028
			Barbless × Peatland, F_2				
1	148.0	10.474	32.55	104.16	− 64.77	0.561	−0.061
2	185.0	7.922	20.90	61.73	94.34	0.646	0.216
3	146.0	8.269	21.80	73.79	76.00	0.725	0.160
4	163.0	7.875	17.30	17.52	−178.23	0.243	−0.596
5	167.0	7.538	16.56	23.59	−138.13	0.350	−0.504
6	186.0	6.047	9.87	17.92	21.80	0.578	0.224
Av.	165.8	8.021	19.83	49.79	− 31.50	0.517	−0.095
			Velvet × Peatland, F_2				
1	168.0	8.402	21.63	93.39	203.48	0.928	0.435
2	178.0	8.178	21.57	64.86	200.79	0.647	0.432
3	183.0	9.082	18.44	26.49	−185.41	0.335	−0.545
4	179.0	5.977	12.44	43.24	190.05	0.985	1.228
5	172.0	6.712	13.73	30.60	20.75	0.601	0.110
6	181.0	5.634	10.66	32.15	100.35	0.924	0.883
Av.	176.8	7.331	16.41	48.46	88.34	0.737	0.424
			Velvet × Korsbyg, F_2				
1	180.0	7.208	18.76	22.26	−258.14	0.274	−0.734
2	167.0	7.428	16.69	30.51	−123.23	0.447	−0.442
3	173.0	7.740	19.91	43.96	− 44.77	0.495	−0.113
4	185.0	7.349	13.80	16.31	− 92.85	0.318	−0.488
5	184.0	6.551	16.68	54.61	203.93	0.802	0.733
6	176.0	5.814	12.90	34.16	80.18	0.737	0.482
Av.	177.5	7.015	16.46	33.64	− 39.15	0.512	−0.094

Positive skewness is clear, all plots giving a positive g_1. The average number of plants per plot was 174. For this number the standard error per plot of g_1 would be 0.184. All plot values of g_1 were positive, 18 of the 24 exceeding twice their standard error. A definite general departure from normal is clear, too many single plant yields piling up at the low yield end of the distribution.

The values of g_2 varied considerably, two of the crosses giving positive means and two negative. The standard error of g_2 for $N = 174$ would be 0.366. The standard error of the variety means would be roughly $0.366 \div \sqrt{6} = 0.150$. Only one cross, Velvet × Peatland, could be judged as having a significant kurtosis and this was positive,

indicating a definite tendency for the yields to pile up in the center of the distribution.

In Table 4 is given the mean squares from an analysis of variance of the k and g statistics of the crosses given in Table 3.

TABLE 4.—*Mean squares of k and g calculated from the F_2 crosses in Table 3.*

Variation due to	D.F.	k_1	k_2	k_3	k_4	g_1	g_2
Blocks.....	5	3.857†	72.32†	1065.74	15,642	0.025	0.240
Varieties....	3	2.534*	19.09	486.81	20,452	0.075	0.361
Error.......	15	0.554	9.27	458.62	21,657	0.050	0.302

*Exceeds the 5% point.
†Exceeds the 1% point.

The varietal means (k_1) of the crosses were significantly different. The variation in k_1 and k_2 in the different blocks was highly significant. All other comparisons were nonsignificant. The distribution

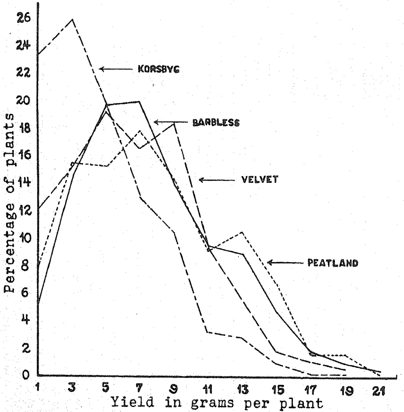


FIG. 1.—Frequency distribution of yield in grams per plant of four varieties of barley.

of the single plant yields in F_2 in these four crosses was essentially the same for all crosses.

In Fig. 1 is presented in graphic form the distribution of the single plant yields of the four varieties used as parents of crosses used in this study. The data from the six replications were combined in drawing these graphs. These curves then represent variation within varieties, the variation between blocks not being removed.

The low average yield of the variety Korsbyg is apparent in Fig. 1. As a consequence, an unduly large percentage of the plants yielded from 0 to 2 grams, leading to a skew distribution. It was shown in Table 2 that these four varieties could not be considered as differing significantly in either skewness or kurtosis, however.

In Fig. 2 is shown the distribution of single plant yields of the four F_2 crosses.

These four crosses, as shown in Table 4, differed significantly in mean yield but not in any other characteristic of the yield distribution. The similarity in form of the distribution curves is evident.

DISCUSSION

In three crosses, Barbless × Peatland, Velvet × Peatland, and Velvet × Korsbyg, it is possible to compare the mean yield of the F_2 plants with the average of the parents. The increase of the F_2 over the average of the parents was 4, 2 and 22%, respectively. This is lower than the average increase of 24% found for six other crosses by

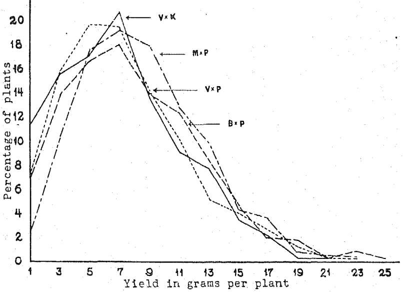


FIG. 2.—Frequency distribution of yield in grams per plant of four F_2 crosses in barley. V × K = Velvet × Korsbyg; M × P = Minia × Peatland; V × P = Velvet × Peatland; B × P = Barbless × Peatland.

Immer (2) where parents and F_2 were grown in rod-row trials at the normal rate of seeding.

The variance of the three crosses Barbless × Peatland, Velvet × Peatland, and Velvet × Korsbyg exceeded the average of the parents by 22, 5, and 29%, respectively. Since there was a general tendency for the variances to increase as the mean yields increased, especially among the parent varieties, a part of this increased variance in F_2 could be attributed to the increase in mean yields. In only one of these three crosses, that of Barbless × Peatland, did the variance of the F_2 appreciably exceed that of the average of the parents when allowance is made for the increased yield in F_2. It seems clear that the yield of an F_2 plant is determined very largely by factors of the environment. This is evident also from a comparison of Figs. 1 and 2.

The distribution of the yields was positively skew, there being an excess of plants with low yields. This tendency becomes more pronounced as the mean yields decrease, as shown by the value of g_1 for Korsbyg. In general, there was little evidence of kurtosis as measured by g_2.

There were no significant differences in k_3, k_4, g_1, or g_2 for either varieties or crosses, indicating that with the exception of the variance the type of distribution for different varieties or crosses was similar. If the yield of single plants is determined largely by factors of the environment such a result is to be expected.

If different varieties or crosses are to be compared, it would appear that only the means, and possibly the variances, would need to be calculated. The yield of single plants in F_2, spaced 5 inches apart, would supply essentially no information on the yield of F_3 progeny rows.

SUMMARY

The type of distribution of single plant yields as measured by the k and g statistics was determined for four varieties and four F_2 crosses of barley.

The varieties and F_2 crosses differed significantly in mean yield and the varieties differed significantly in variance of plant yields within plots.

The distribution curves were positively skew but lacked kurtosis. The degree of skewness between varieties or crosses did not vary significantly.

The variation in yield of single plants in spaced progeny rows is determined almost completely by environmental factors.

LITERATURE CITED

1. Fisher, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 7. 1938.
2. Immer, F. R. Relation between yielding ability and homozygosis in barley crosses. Jour. Amer. Soc. Agron., 33: 200–206. 1941.

CAROTENE CONTENT OF TEXAS RANGE FORAGES[1]

A. R. KEMMERER, J. F. FUDGE, AND G. S. FRAPS[2]

CAROTENE is widely distributed in the plant kingdom and is an important source of vitamin A potency for domestic animals. According to some reports, range grasses or forages may not always afford sufficient carotene to satisfy the vitamin A requirements of grazing animals.

Hart and Guilbert (7)[3] found range cattle suffered from vitamin A deficiency under natural range conditions following severe drought. Fraps, Copeland, and Treichler (2) reported that ordinary hays and fodders do not supply sufficient vitamin A to enable dairy cows to produce butter fat high in vitamin A. According to Myburgh (11), the carotene content of pasture plants in South Africa diminished rapidly as the plants matured or as they became dry during the winter season or during periods of drouth. Atkeson, *et al.* (1) reported that pasture plants were relatively high in carotene during the early summer and fell off during the hot summer months. Smith and Stanley (12) found that blue grama grass was rich in carotene in the early stages of growth, but for the greater part of the year it was relatively low. Moon (9) reported that the carotene content of grass was depressed by drouth and that stage of growth had much to do with the carotene content. Young grasses were higher in carotene than grasses in the blooming stage. Carotene was also less in plants that had been damaged by frost. Other workers have made like observations.

In the work presented here the object was to determine the carotene content of various range grasses in different stages of growth and conditions and to ascertain their value for satisfying the vitamin A requirement of grazing animals.

EXPERIMENTAL PROCEDURE

The range forages were collected during the summer and winter of 1941. The dried and dormant grasses were ground in a Wiley mill and placed in cold storage until after the carotene analyses were completed. The fresh green grasses were put in jars, covered with methanol, and stored in a refrigerator. On analysis the methanol was poured off, the residue ground in a food chopper, and carotene and moisture determined on it. Fraps, Meinke, and Kemmerer (6) have shown that methanol prevents the destruction of carotene in fresh green material and does not dissolve appreciable amounts of carotene. The crude carotene was determined by the A.O. A.C. method for carotene in dried hays and grasses. The crude carotene fraction of a limited number of the dried grasses was analyzed by the complete chromatographic method previously reported (5).

The carotene contents on the dry basis of fresh green forages arranged in Table 1 to show the distribution of the values of the various samples varied from 495

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Tex. Presented at the Memphis, Tenn., meeting of the American Chemical Society, April 1942. Received for publication May 25, 1942.

[2]Chemists and Chief of Division, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 855.

p. p. m. crude carotene for Dallis grass to 2 p. p. m. for sotol bulbs. Considerable variations were found in the same kind of plants. Plants in the blooming stage were relatively lower in carotene than young immature plants. The carotene content of dried and dormant forages (Table 2) varied from 94 p. p. m. for half-dry buffalo grass to 2 p. p. m. for dry mature Bermuda grass. The chromatographic analyses of some of these dried forages (Table 3) showed that the crude carotene of the grasses contained from 61 to 94% of beta carotene, while crude carotene of silage contained only from 58 to 64%.

DISCUSSION OF RESULTS

Carotene requirements of cattle are the lowest on maintenance ration or when they are being fattened with some growth. Under these conditions according to Jones, *et al.* (8), 1,500 micrograms per 100 pounds of live weight appear to be sufficient to sustain health and produce good growth, but this amount is not sufficient to prevent night blindness. Carotene requirements for reproduction and lactation are higher than those for maintenance or fattening. Since range cattle produce only enough milk to feed the calves, their requirements for milk production are much less than those of dairy cows. Fattening cattle consume approximately 2 pounds of feed per 100 pounds of live weight when the feed is palatable (10). With this quantity of feed, 1.7 parts of carotene per million parts of feed would be sufficient. When the feed is unpalatable, as with dried range grasses, the consumption is smaller; thus at the time when the carotene is low, the consumption of the forage is also smaller than at other times. There is also a possibility of lower utilization of carotene in the dried grass. Taking all these factors into consideration, it appears probable that a carotene content of not less than 4 p. p. m. may be needed in range forages.

The fresh green grasses and the clovers listed in Table 1 contained from 64 to 495 p. p. m. of crude carotene on the dry basis. Most of the samples contained from 100 to 200 p. p. m. These quantities are ample for maintenance, and will also allow some storage of vitamin A in the liver. The other fresh forages contained from 2 to 105 p. p. m. With the exception of the sotol bulbs and possibly prickly pear leaves, all contained sufficient carotene for maintenance of range animals.

The crude carotene content of the dried or dormant grasses ranged from 4 to 94 p. p. m. Dried Bermuda grass and one sample of dried buffalo grass did not contain sufficient carotene for maintenance of range cattle, but the remaining 36 samples contained sufficient quantities. Under normal conditions, dried range forage apparently contains sufficient carotene for range animals. Under some conditions, such as a prolonged drouth, carotene may be deficient. The conditions under which carotene deficiency occurs need more study with special attention to the carotene content of grasses and other forages after prolonged dry periods.

The beta carotene content of the dried forages, as ascertained by the chromatographic method of analysis (Table 3), ranged from 61 to 94% of the crude carotene; in most of the grasses about 80%. The lowest percentage was in the three samples of Georgia grass, ranging

TABLE 1.—*Crude carotene content of fresh green forages on dry basis.*

Plant	Carotene, p.p.m.
Grasses	
Beard, silver, *Andropogon saccharoides*	262.
Bermuda, *Cynodon dactylon*	413, 361, 281, 187, 174.
Bluegrass, Texas, *Poa arachnifera*	289.
Buffalo, *Buchloe dactyloides*	254, 226, 207, 179, 169, 167, 155, 146, 125, 102, 99.
Curly mesquite, *Hilaria belangeri*	222, 177, 142, 134, 128, 112.
Dallis, *Paspalum dilatatum*	495, 372, 227.
Finger, black, *Chloris cucullata*	165, 119.
Grama, hairy, *Bouteloua hirsuta*	122.
Grama, red, *Bouteloua trifida*	155, 119, 64, 70.
Grama, Texas, *Bouteloua rigidiseta*	199, 122, 68.
Grapevine mesquite, *Panicum obtusum*	136.
Indian, *Sorghastrum nutans*	373.
Johnson, *Sorghum halepense*	366, 365.
Knot, *Paspalum distichum*	220.
Panicum fasciculatum	495.
Paspalum stramineum	407.
Rescue, *Bromus catharticus*	406.
Rhodes, *Chloris gayana*	283.
Rye, Italian, *Lolium multiflorum*	374.
Spear, *Stipa leucotricha*	274.
Other Forages	
Clover, bur, *Medicago hispida*	364.
Clover, sweet, *Melilotus alba*	418.
Cactus, spineless, *Opuntia Ellisiana*	33.
Guajillo, *Acacia Berlandieri*	105.
Mesquite leaves, *Prosopis chilensis*	44.
Live oak leaves, *Quercus* sp.	55.
Post oak leaves, *Quercus* sp.	114, 81.
Prickly pear leaves, *Opuntia* sp.	6.
Sotol bulbs, *Dasylerion texanum*	2.
Sotol leaves, *Dasylerion texanum*	42.

TABLE 2.—*Crude carotene content of dried and dormant grasses.*

Grass	Carotene, p.p.m.
Bermuda, *Cynodon dactylon*	2.
Little bluestem, *Andropogon scoparius*	26.
Silver beard, *Andropogon saccharoides*	14, 8.
Buffalo, *Buchloe dactyloides*	94, 34, 31, 26, 25, 22, 19, 15, 7, 4.
Crowfoot, *Chloris subdolichostachya*	44, 26, 16, 8.
Curly mesquite, *Hilaria belangeri*	73, 60, 34, 8, 6.
Dallis, *Paspalum dilatatum*	15.
Blackfinger, *Chloris cucullata*	22, 21, 14, 12.
Hairy grama, *Bouteloua hirsuta*	18, 8, 8.
Sideoats grama, *Bouteloua curtipendula*	10.
Texas grama, *Bouteloua rigidiseta*	50, 26.
Needle, *Aristida Wrightii*	13.
Panic, *Panicum fasciculatum*	25.
Sandhill, *Brachiaria ciliatissima*	6.
Tobosa, *Hilaria mutica*	13.

from 61 to 66%. The silages, of course, are not range forages but are included as a matter of interest. The beta carotene content of the crude carotene of these ranged from 58 to 64%. The beta carotene content of several fresh grass samples ranged from 94 to 98%.

TABLE 3.—*Chromatographic analyses of dried and dormant forages.*

Forage	Beta carotene, p.p.m.	Impurity, p.p.m.	Beta carotene as percentage of crude carotene
Black finger grass, *Chloris cucullata*	9.1	1.3	87.4
Buffalo grass, *Buchloe dactyloides*	22.5	3.2	87.6
Buffalo grass, *Buchloe dactyloides*	18.5	2.9	86.6
Crowfoot grass, *Chloris subdolichostachya*	10.5	1.4	88.3
Crowfoot grass, *Chloris subdolichostachya*	4.5	1.2	79.0
Curly mesquite grass, *Hilaria belangeri*	26.3	4.5	85.4
Georgia grass, *Paspalum plicatulum*	12.9	8.2	61.1
Georgia grass, *Paspalum plicatulum*	9.3	4.0	69.7
Georgia grass, *Paspalum plicatulum*	0.8	0.4	66.7
Hairy grama grass, *Bouteloua hirsuta*	11.3	1.7	87.0
Hairy grama grass, *Bouteloua hirsuta*	4.5	1.2	79.0
Sage grass, *Andropogon littoralis*	6.3	1.2	84.0
Sandhill grass, *Brachiaria ciliatissima*	2.2	0.6	78.5
Texas grama grass, *Bouteloua rigidiseta*	23.1	2.5	90.4
Tobosa grass, *Hilaria mutica*	7.8	0.5	94.0
Kafir silage, *Sorghum vulgare*, dry basis	10.0	7.2	58.0
Kafir silage, *Sorghum vulgare*, dry basis	6.2	4.2	59.6
Sumac silage, *Sorghum vulgare*, dry basis	22.1	13.9	61.4
Sumac silage, *Sorghum vulgare*, dry basis	15.0	8.4	64.0

Dairy cattle require much greater amounts of vitamin A for milk production than do beef cattle for fattening. According to Fraps, *et al.* (3), dairy cows require approximately 535,000 to 1,000,000 micrograms of carotene daily to produce butter high in vitamin A potency. In order to obtain this amount of carotene, a dairy cow would need to eat the equivalent of 12 to 23 pounds dry weight of fresh forages containing 100 p. p. m. of carotene on the dry basis. Most of the fresh green forages (54 out of 62) would furnish enough carotene for a dairy cow to produce butter fat high in vitamin A. Only one of the dried forages (Table 2) would give enough carotene for butter quite high in vitamin A.

SUMMARY

Green forages contained from 495 p. p. m. of carotene in Dallis grass to 2 p. p. m. in sotol bulb. Fifty-four out of 62 fresh range forages would supply enough carotene to enable range cattle to store vitamin A or to enable dairy cattle to produce butter fat quite high in vitamin A.

The carotene content of dried and dormant forages ranged from 2 to 94 p. p. m. of carotene. Practically all of the dried and dormant grasses would supply enough carotene for maintainence requirements

of 1,500 micrograms per 100 pounds live weight of beef cattle, but not enough for dairy cows to produce milk high or even fair in vitamin A. During a prolonged drouth, lower quantities are probably present.

The crude carotene fraction of silage was found to consist of from 58 to 64% beta carotene, and of dormant grasses from 61 to 94% beta carotene.

LITERATURE CITED

1. ATKESON, F. M., PETERSON, W. J., and ALDOVS, A. E. Observation on the carotene content of some typical pasture plants. Jour. Dairy Sci., 20:557–562. 1937.
2. FRAPS, G. S., COPELAND, O. C., and TREICHLER, R. The vitamin A requirements of dairy cows. Tex. Agr. Exp. Sta. Bul. 495. 1934.
3. ———, ———, ———, and KEMMERER, A. R. Utilization of vitamin A by dairy cows. Tex. Agr. Exp. Sta. Bul. 563. 1937.
4. ——— and KEMMERER, A. R. Improved method for estimating carotene in feeds. Jour. Assoc. Off. Agr. Chem., 22:190–195. 1939.
5. ———, ———. Determination of carotene and cryptoxanthin in yellow corn. Ind. & Eng. Chem., Anal. Ed., 13:806–809. 1941.
6. ———, MEINKE, W. W. and KEMMERER, A. R. Determination of pure carotene in green vegetables and green feeds. Jour. Assoc. Off. Agr. Chem., 24:740–744. 1941.
7. HART, G. H., and GUILBERT, H. R. Vitamin A deficiency as related to reproduction in range cattle. Calif. Agr. Exp. Sta. Bul. 560. 1933.
8. JONES, J. M., *et al.* Carotene requirements of range cattle for fattening. In press.
9. MOON, F. E. The composition of grasses at various stages of maturity and the changes occurring during hay making with particular reference to carotene content. Empire Jour. Exp. Agr., 7:225–234. 1939.
10. MORRISON, F. B. Feeds and Feeding. Ed. 20. 1936. (Page 1005.)
11. MYBURGH, S. J. The carotene content of some South African feeds. Onderstepoort Jour. Vet. Sci., 5:475–482. 1935.
12. SMITH, M. C., and STANLEY, E. B. The vitamin A value of blue grama range grass at different stages of growth. Jour. Agr. Res., 56:69–71. 1938.
13. TREICHLER, RAY, KEMMERER, A. R., and FRAPS, G. S. The utilization of carotene and vitamin A in the rat. In press.

CHANGES IN THE PROPORTION AND YIELD OF ALFALFA AND KOREAN LESPEDEZA IN MIXTURES WITH GRASSES[1]

D. W. MAYS, JR.[2]

SINCE each plant in a hay meadow or pasture mixture is influenced in some way by the presence of other plants, the relative abundance of any one species in the mixture may not remain the same seasonally or annually. This change, often undesirable, may in time result in a community very unlike the original one.

This paper reports data on the changes in stand and yield of alfalfa when grown alone and in association with Johnson grass (*Sorghum halepense*) and of Korean lespedeza (*Lespedeza stipulacea*) when grown alone and in association with Johnson grass, Dallis grass (*Paspalum delatatum*), and Bermuda grass (*Cynodon dactylon*).

METHODS

These experiments were conducted at Pine Bluff, Ark., on Ruston sandy loam, an upland low productive soil with a pH of 5.2, and Trinity clay, a lowland soil with a pH of 7.5. The former soil usually suffers drought in midsummer or early fall or both, and the latter soil is subject to being flooded, usually in late winter or early spring.

On each of these soils, seedbeds were prepared in the late fall of 1934. Superphosphate was applied at the rate of 400 pounds per acre and at a depth of 6 inches below the soil surface by drilling it by hand, following a Georgia stock plow. With the exception of Korean lespedeza, which was sown in early March, seedings were made in late October on plots 4 feet by 4 feet in area surrounded by 2-foot borders. Seeds were broadcast and raked into the upper ¼ inch of the soil. After seeding the plots received no cultivation until the following spring (1935).

RESULTS

EXPERIMENTS WITH ALFALFA AND JOHNSON GRASS

On the Trinity clay soil, triplicate plots were seeded to alfalfa at the rate of 15 pounds per acre and to an alfalfa-Johnson grass mixture at the rate of 15 pounds each of alfalfa and Johnson grass. On each of the latter plots, Johnson grass roots were planted at the rate of 1.5 tons per acre the following spring (1935). These roots were equally distributed on each plot and forced into the upper inch of the soil by use of fork-pointed sticks. When Johnson grass leaves appeared, which was an indication that the roots were well established, all plots were raked thoroughly. After this cultivation, the plots received no cultivation throughout the experiment.

Three cuttings were made annually, at which time the plants were separated by hand and put into shrinkage bags. Results on an air-dried basis are reported in Table 1.

[1]Contribution from the Department of Agronomy of the A. M. and N. College, Pine Bluff, Arkansas. Received for publication June 10, 1942.

[2]Director and Agronomist.

TABLE 1.—*Change in percentage of alfalfa in four years when grown in association with Johnson grass on Trinity clay soil at Pine Bluff, Ark., 1935–38.**

Year	Date of cutting	Alfalfa grown alone, yields in lbs. per acre	Alfalfa-Johnson grass mixture, yield in lbs. per acre			
			Alfalfa	Johnson grass	Total	% alfalfa in mixture
1935	June 6	5,340	2,820	3,680	6,500	37.1
	July 20	6,060	3,190	2,200	5,390	59.2
	Sept. 10	3,590	2,710	1,810	4,520	60.0
Total..		14,990	8,720	7,690	16,410	53.1
1936	June 6	4,230	3,590	1,600	5,190	69.1
	July 20	5,420	4,500	2,160	6,660	67.5
	Sept. 10	2,310	1,450	1,990	3,440	42.1
Total..		11,960	9,540	5,750	15,290	62.4
1937†	June 6	3,050	1,260	2,630	3,890	32.4
	July 20	2,580	1,650	3,770	5,420	30.4
	Sept. 10	770	550	6,250	6,700	8.1
Total..		6,400	3,450	12,650	16,010	21.6
1938	June 6	3,650	630	3,320	3,950	15.9
	July 20	1,600	260	4,850	5,110	5.1
	Sept. 10	230	80	4,370	4,450	1.1
Total..		5,480	970	12,540	13,510	7.2

*Average of three replicates.
†Plots were flooded early in February and remained under water 2 days.

EXPERIMENTS WITH KOREAN LESPEDEZA AND GRASSES

On the Ruston sandy loam soil, triplicate plots were seeded to Korean lespedeza and mixtures of Korean lespedeza and Johnson grass, Korean lespedeza and Dallis grass, and Korean lespedeza and Bermuda grass. Poor stands were obtained from fall seeding (1934) and each plot was reseeded at the same rate in early March, 1935. In addition, roots of each of these grasses were planted at the rate of 1.5 tons per acre on their respective plots. This insured good stands of these grasses the first year. Each plot was raked lightly when the Korean lespedeza had reached a height of 2½ inches. After this, the plots received no cultivation throughout the experiment.

One cutting was made annually, about the middle of August, and plants were separated and cured by the same method used in harvesting the alfalfa-Johnson grass mixture. Results on an air-dry basis are reported in Table 2.

DISCUSSION

A much higher yield of alfalfa was obtained from the superphosphate-treated plots than adjacent untreated plots. Probably the unusually high alfalfa yields obtained in this experiment were due to

TABLE 2.—*Korean lespedeza grown alone and in mixture with Johnson grass and Bermuda grass on Ruston sandy loam soil in Pine Bluff, Ark., 1935-37.**

Crop	Rate of seeding in lbs. per acre	Total hay yield					
		1935		1936		1937	
		Lbs. per acre	% Korean	Lbs. per acre	% Korean	Lbs. per acre	% Korean
Korean alone....	15	1,450	—	940	—	1,330	—
Korean and Johnson grass......	15 each + 1.5 T. Johnson grass roots	2,048	30.2	1,431	16.0	2,080	5.8
Korean and Dallis grass.......	15 each + 1.5 T. Dallis grass roots.	1,654	51.0	1,568	45.9	939	51.9
Korean and Bermuda grass....	15 each + 1.5 T. Bermuda grass roots	1,533	81.6	700	60.0	674	4.4

*Average of three replicates.

the application of superphosphate and the time and depth to which it was placed in the soil. It has been reported[3] that alfalfa yields were increased 100 to 179% over nontreated areas by placing superphosphate 4 to 8 inches below the surface of the soil. In the southern states, it is suggested[4] that fall applications of phosphorus fertilizers are more effective than spring applications. Korean lespedeza, a shallow-rooted plant compared with alfalfa, did not respond to superphosphate placed 6 inches below surface of the soil. Unpublished data indicate that Korean lespedeza responds best to superphosphate when placed 1½ to 3 inches below surface of the soil. What effect different depths of placing fertilizers in the soil have on the changes that take place in pastures and hay meadows is not known with certainty, but it seems logical that they are responsible for many changes and the times at which these changes take place. It is a common practice to mow regularly and graze heavily to eradicate weeds in pastures and occasionally in hay meadows. This suggests the possibility that farm cultural practices such as mowing, harrowing, rolling, disking, burning, and grazing pastures or meadows affect the yields of crops differently. Such practices must be considered in accounting for the changes and the time in which they take place in these areas.

SUMMARY AND CONCLUSIONS

An experiment was conducted on Ruston sandy loam soil at Pine Bluff, Ark., in 1935–37 to determine the yield and change in population of Korean lespedeza when grown alone and in association with

[3]HOCKENSMITH, R. D., GARDNER, ROBERT, and KEZER, ALVIN. The effect of depth of placement on the availability of superphosphate in calcareous soils. Soil Sci., 36:35–39. 1933.

[4]ROBINSON, R. R. Phosphorus fixation as affected by soil temperature. Jour. Amer. Soc. Agron., 34:301–306. 1942.

Johnson grass, Dallis grass, and Bermuda grass. A similar experiment was conducted on Trinity clay soil in 1935–38 to determine the yield and change in population of alfalfa when grown alone and in association with Johnson grass. Both soils received superphosphate placed at a depth of 6 inches below the soil surface.

The investigation indicates that Korean lespedeza is replaced by Johnson grass in a Korean-lespedeza-Johnson grass mixture and by Bermuda grass in a Korean-lespedeza-Bermuda grass mixture. Apparently, Korean lespedeza and Dallis grass reach an edaphic climax in a Korean-lespedeza-Dallis grass mixture, yielding 50% Korean lespedeza and 50% Dallis grass. Alfalfa is replaced by Johnson grass when grown in an alfalfa-Johnson grass mixture.

NOTES

A DISC SCARIFIER FOR KUDZU SEED

A LOCALLY constructed disc scarifier at the Soil Conservation Service nursery, Rock Hill, S. C., scarifies seed of kudzu, *Pueraria thunbergiana*, Benth., more efficiently than either sulfuric acid or three other mechanical scarifiers. The disc scarifier (Fig. 1) was constructed by Nursery Manager W. H. Rhodes and V. L. Crook, automobile mechanic, at the suggestion of the writer. It is a modification of one developed previously and used by the U. S. Forest Service for scarifying seed of forest trees.[1]

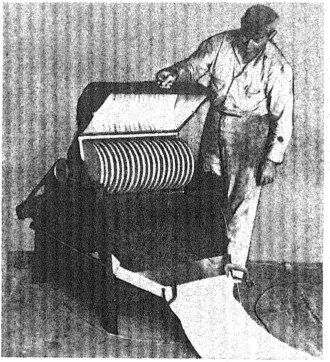


FIG. 1.—Scarifier with cover raised. A batch of scarified kudzu seed is being emptied from the scarifier.

Kudzu seed have relatively thick brittle seedcoats difficult to scarify adequately without cracking. The new disc scarifier gently grinds these seedcoats without cracking the most fragile coats. This type of seed scarifier might be used advantageously in scarifying hard brittle seed of other agronomic crops. Details of construction and operation of the disk scarifier will be furnished interested agrono-

[1]Jour. For., 33:66–74, 1936; 35:396–398, 1937.

mists and conservationists.—PAUL TABOR, *Soil Conservation Service. U. S. Dept. of Agriculture, Spartanburg, S. C.*

BIOLOGICAL EXPERIMENTS WITH IODINE

IN an experiment with iodine in relation to the nutrition of alfalfa the rate of its growth and its general appearance was improved by trace amounts of iodine only when the culture solutions had aged about 2 weeks in the presence of growing alfalfa roots. In the analysis of the culture solutions the rate of nitrogen loss could roughly be correlated to the initial concentration of iodine up to ½ p.p.m. In another experiment inoculated alfalfa grown aseptically in sand which contained a similar culture solution except that nitrogen was absent did not show any stimulation with any amounts of iodine up to 5 p.p.m. These observations prompted an inquiry into the effect of iodine on certain bacteria and on some chemical reactions known to be instituted by the micro-flora of the soil.

The rate of carbon dioxide liberated by the decomposition of starch in a soil of good fertility was studied. The results showed that when ½ mg of iodine and 10 grams of starch were thoroughly mixed with a kilogram of this soil and water added to 60% of saturation, a decomposition of 20.5% of the starch carbon was realized in 60 days, whereas without added iodine 17.6% of the carbon was decomposed. No significant variations in the bacteria or mold counts were observed at the 60-day interval. With 5 mg of iodine, 16.7% of the starch carbon was decomposed. The higher iodine treatment produced conditions for a low count of bacteria and a high count of molds at the end of the 60-day interval.

The nitrification rate of ammonium sulfate was studied by inoculation with three soils, one each of high, intermediate, and low fertility. This was done in buffered nutrient solution containing 32 milligrams of nitrogen added as ammonium sulfate in 100 grams of quartz sand and 10 grams of the soil. The iodine treatment included was 0.1 mg of iodine. The rate of nitrification was doubled when the soil of poor fertility was used; however, no stimulation occurred when soils of intermediate and high fertility were used.

Nitrogen fixation rates were studied by use of a soil of low fertility to which sufficient lime was added to bring it to a pH of 7 and sufficient starch added to increase the carbon content by 0.8%. The soil was inoculated with azotobacter. At the end of 3 months the soils had increased to some extent in total nitrogen and more nitrogen was fixed when the treatments 0.05 mg and 0.15 mg of iodine per 100 grams of soil were used than when this element was not added. No effect was observed when a soil of high fertility was used.

The rate of division of *Rhizobium meliloti* for a period of 18 hours was measured at two levels of iodine in inoculated culture solutions aerated only by occasional shaking. Seventeen times the original number were present at 18 hours with 0.01 mg and 0.1 mg of iodine per 100 cc, whereas 8.5 times the original number were present when no iodine was added. No positive stimulation in rate of division was experienced with *Escherichia coli*.

It seems that these data indicate that the stimulation of plant growth by any factor suspected of being essential can be caused by things totally unrelated to its assimilation as a necessary factor of growth. Yield increase of a crop as evidence that any element is essential or as indicating a deficiency of any element added in small amounts to the soil may be misleading. The effect of the element on the soil's microflora should also be evaluated, since such changes may affect the nutrition of the plant under study.—W. E. CARLSON, *Montana State College, Bozeman, Mont.*

BOOK REVIEW

RANDOM SAMPLING DISTRIBUTIONS

By Alan E. Treloar, Minneapolis: Burgess Pub. Co. 94 pages, illus. 1942. Mimeoprint, flexible binding. $2.25.

PROBABLY every student of statistics at the beginning of his studies and even later has been confused by the different methods used in analyzing small sample data. What he fails to appreciate is the different types of probability distributions applicable to small sample theory and how rapidly these approach the normal distribution as n is increased. In this book Doctor Treloar explains, compares, and illustrates by graphs the characteristics of each distribution, at the same time presenting the algebra necessary for the student to analyze his data. The approach is from the chronological point of view showing how mathematicians from "Student" to Fisher have advanced these studies which are of inestimable value to investigators who are limited to a small number of observations. These critical comparisons are probably the most important phase of the book.

The work is quite thorough, well written, concise, and includes some of the author's own investigations. It should be valuable to biologists and others who deal with small samples. To those who desire to pursue the studies more thoroughly, each chapter ends with references to the original publications.

The scope of the work is indicated by the chapter titles which are statistical bases of inference; the randon sampling distribution of means; random sampling differences between means; sampling errors of the standard deviation; the estimation of σ from s; comparison of standard deviations: Fisher's z distribution; Student's distribution; significant differences and Student's distribution; the analysis of variance; the sampling errors of the correlation coefficient. The appendix tables include a table for estimating σ from s on the basis of assumptions concerning the position of s in its random sample distribution; Snedecor's table for the distribution of F; table of the probability of t, based on n degrees of freedom will exceed certain values; and tables of z_r as a function of r. An index completes the volume. (F. Z. H.)

AGRONOMIC AFFAIRS

CENSORSHIP AND THE FOREIGN MAILING LIST OF THE JOURNAL

BECAUSE the JOURNAL contains articles dealing with new scientific and technical processes, it comes under the jurisdiction of the Technical Data License Division of the Board of Economic Warfare of the Office of Censorship if it is sent out of the United States. Advance proofs of each number of the JOURNAL are submitted to the Technical Data License Division for examination and licensing prior to mailing to the foreign list.

Thus far, no questions have been raised regarding any material appearing in the JOURNAL. Contributors to the JOURNAL should take note, however, of the weather clauses of the Code of Wartime Practices for the American Press and U. S. Postal Censorship Regulations. The chief danger of transgressing censorship regulations so far as the JOURNAL is concerned lies in the matter of weather data. There is no objection to the export of weather data for periods prior to December 1, 1941. There is objection, however, to the export of daily, monthly, or yearly summaries of meteorological data covering periods subsequent to December 1, 1941. Appearance of such data in the JOURNAL would necessitate the deletion of the pages carrying the data or the withholding of that particular number from all foreign subscribers.

Enemy countries and countries occupied or controlled by the enemy are closed to the JOURNAL.

MEETING OF THE WESTERN SOCIETY OF SOIL SCIENCE

THE nineteenth annual meeting of the Western Society of Soil Science was held at the University of Utah, Salt Lake City, Utah, June 15 to 20, with representation from all of the eleven western states. A total of 26 papers on current research were presented during the four half-day sessions. In addition, three papers were presented on a symposium on "Organic Matter in Relation to Plant Growth" under the chairmanship of Dr. W. P. Kelley in which the soil scientists collaborated with plant physiologists and horticulturists. Mimeographed abstracts of most of the papers have been prepared by the Secretary-Treasurer, Professor W. P. Martin of the University of Arizona, Tucson, Ariz., to whom we are also indebted for this account of the meeting.

Field trips included the examination of soil profiles peculiar to the Salt Lake Valley under the direction of Professor D. S. Jennings; the Davis County Water-shed Conservation Project of the Intermountain Range and Forest Experiment Station under the direction of Dr. George Stewart; and the sand culture installations of the Agricultural Research Department of the American Smelting and Refining Company, with Dr. M. D. Thomas in charge.

The 1943 meeting of the Society will be held in Corvallis, Oregon, the third week in June. Officers of the Society for the coming year include T. L. Martin, Brigham Young University, Provo, Utah, Presi-

dent; O. C. Magistad, U. S. Regional Salinity Laboratory, Riverside, Calif., Vice President; and W. P. Martin, University of Arizona, Tucson, Ariz., Secretary-Treasurer.

PLANS FOR THE 1942 MEETINGS OF THE AMERICAN SOCIETY OF AGRONOMY AND THE SOIL SCIENCE SOCIETY OF AMERICA

THE need for a national meeting for exchanging ideas on the many new situations arising as a result of the war seems more acute in 1942 than in peacetime. It is the unanimous opinion of the Division of Biology and Agriculture of the National Research Council, "that the cancellation of scientific meetings would retard rather than advance the war services of the societies concerned."

In view of this sentiment it has been decided to proceed with the national meetings as planned. The meetings will be held in the Hotel Statler in St. Louis, November 11 to 13. Soil and crop problems arising as a result of the war will receive special emphasis. While total attendance will probably be small because of transportation difficulties, it is hoped that every state and federal agency vitally concerned with soil and crop problems will send at least one representative to these meetings. We can learn much from each other as to how we can best solve these important national problems.

The general program of the American Society of Agronomy will include papers by Dr. F. W. Parker recently connected with the Fertilizer Division of the OPA on "The Fertilizer Situation and the War" and by Dr. O. S. Aamodt of the Bureau of Plant Industry, U. S. Dept. of Agriculture on "The Seed Situation and the War". The general program of the Soil Science Society will deal with three phases of soil organic matter and the general program of the Crops Section will include papers on weed control, emergency crops vital to the war effort, and observations on agriculture and agricultural research in Chile, Argentina, and Uruguay.

NEWS ITEMS

DOCTOR J. A. NAFTEL of the Alabama Polytechnic Institute at Auburn, Ala., entered upon military duty as a First Lieutenant in Field Artillery on July 21 and for the present is stationed at Fort Bragg, N. C.

—A—

C. E. BORTNER, Assistant Agronomist in the Kentucky Agricultural Experiment Station, has joined the Chemical Warfare Division of the Army and will be stationed at Gadsden, Alabama.

JOURNAL

OF THE

American Society of Agronomy

VOL. 34 OCTOBER, 1942 No. 10

RESPONSES OF BIENNIAL SWEET CLOVER TO MOISTURE, TEMPERATURE, AND LENGTH OF DAY[1]

T. JACKSON SMITH[2]

THE factors affecting root storage of biennial sweet clover have been little investigated. Several workers (3, 8, 9, 10)[3] have found that there is little storage in the roots in April, May, and June, but that large amounts of reserve food materials are stored in the roots in the fall. Pieters (5) obtained longer internodes of *Melilotus alba*, and Roberts and Struckmeyer (6) a greater height of *M. dentata* under long day lengths.

The primary purpose of the investigations reported here was to determine the factors responsible for the large variations in the growth of tops and storage in the roots of sweet clover at different seasons of the year. This report includes data on the effect of day length on root-top ratios, total weight of roots and tops, height of plants, blooming, crown buds, and the content of certain carbohydrate and nitrogen fractions in the roots and tops. Limited observations were made on the effect of soil moisture supply on root and top growth. The effects of temperature on root and top growth, on blooming, and on the initiation and subsequent growth of crown buds were also observed.

MATERIALS AND METHODS

These investigations extended from the fall of 1937 until the spring of 1941. Miami silt loam soil was used for all experiments, both in the field and in the greenhouses. Since this soil is normally quite acid, sufficient high grade limestone was added in all tests to bring the soil up to pH 6.5.

In harvesting plants grown in pots, all roots and tops were saved. From the plants grown in the field only the roots in the top 12 inches of soil were harvested. Roots extending below this depth were cut off at the 12-inch level.

[1]Part of a thesis presented to the Department of Agronomy, Ohio State University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Received for publication April 27, 1942.

[2]Formerly agent, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and Research Assistant Ohio Agriculture Experiment Station, Columbus, Ohio; now Assistant Agronomist, Arizona Agricultural Experiment Station, Tucson, Ariz. The author wishes to express his appreciation to Dr. C. J. Willard, Professor of Agronomy, Ohio State University, for suggestions and guidance.

[3]Figures in parenthesis refer to "Literature Cited", p. 875.

Melilotus officinalis was seeded in pots on August 21, 1937 and kept outdoors until October 2 when the pots were transferred to the greenhouse. These were divided into two groups of 30 pots each, one group being placed in a warm section of the greenhouse and the second in a cool section of the greenhouse. Differences in temperature were obtained by keeping the cool section well ventilated. In both the cool and warm sections, plants were grown under both normal fall day lengths (average 11 hours) and under 17-hour day lengths.

On April 18 and again on July 16, 1938, both *M. alba* and *M. officinalis* were seeded in the field. From August 2 until October 23, one-half of the plants from each date of seeding received sufficient artificial light each night to make a 16-hour day. Plant harvests were made on July 7 and October 23. Small areas from each date of planting and length of day were left and notes on winterkilling and growth were made on them during late winter and the following spring.

Both *M. alba* and *M. officinalis* were seeded in the field on March 25, 1939, to obtain additional data on root and top growth under different day lengths. These plants were divided into three groups, one group being kept under each of the following day lengths: 9-hour day, normal day (average 14.1 hours), and 17-hour day.

Seedings of *M. officinalis* were made on June 23 and also on August 16, 1939, to obtain further data on the effects of temperature and day length on root and top growth. After September 2 temperature variations were obtained by growing one series of plants in the warm greenhouse and the others outside. Plants were grown outside under normal day lengths (average 13.1 hours for June 23 seeding and 12 hours for August 16 seeding), and inside under both normal and 17-hour day lengths.

M. officinalis was grown in the field from June 23 to August 30, 1939, to obtain data on the relative root and top growth under wet and dry soil conditions. The experiment consisted of two plots, each 2 square yards in area. One received only normal rainfall, while the other was watered to a depth of 12 to 15 inches at least once and often twice weekly.

Additional seedings of both *M. alba* and *M. officinalis* were made in pots at various times during 1938 and 1939 in order to study the effect of temperature and length of day on crown bud formation and blooming.

Duplicate determinations of alcohol-soluble nitrogen, total nitrogen, total sugars, starch, and total reserve polysaccharides were made from two 100-gram samples of tops and roots of plants grown under each of the different day lengths seeded on August 2, 1937, and on April 18 and July 16, 1938.

Total nitrogen.—Determinations for nitrogen in both the extract and the dry residue were made by the official Kjeldahl method (4).

Total sugars.—After inversion with invertase, invert sugars were determined according to the Shaeffer-Hartman procedure (7).

Starch.—After treatment with taka-diastase, reducing sugar tests were run on aliquot samples. Starch is expressed in terms of dextrose.

Total reserve polysaccharides.—Samples were hydrolyzed with a 0.5% solution of hydrochloric acid and free reducing sugar tests were run on the neutralized solution. Polysaccharides are given in terms of dextrose. The total carbohydrates were determined by adding the amount of total sugars to the amount of total polysaccharides.

EXPERIMENTAL RESULTS

In all experiments, with both *Melilotus alba* and *M. officinalis*, length of day had a pronounced and definite effect upon top growth and root storage. In all cases where sweet clover was grown under different day lengths, the shorter the day length the greater the proportion of the total weight that was produced in the roots, as shown by Table 1.

TABLE 1.—*Effect of day length on the proportion of roots in the total weight of sweet clover.*

Date seeded	Date harvested	Length of day, hrs.		Proportion of roots in total dry weight			
				Melilotus alba		*Melilotus officinalis*	
		Long day	Short day	Long day, %	Short day, %	Long day, %	Short day, %
Aug. 21, 1937	Dec. 20	17	Normal (av. 11)	—	—	11.8	64.1
July 16, 1938	Oct. 23	16	Normal (av. 12.6)	13.4	42.7	9.7	44.4
Mar. 26, 1939	July 7	17	9	8.2	22.6	11.0	28.2
June 23, 1939	Nov. 2	17	Normal (av. 13)	—	—	15.4	38.0

The proportion of roots in the total weight is less for plants grown under long days because of both increased top growth and decreased root storage. Under the longer day lengths, particularly 16 to 17 hours, the internodes elongate rapidly and the amount of top growth is considerably increased over plants grown under shorter days. Almost no elongation of internodes took place when plants were exposed to day lengths shorter than 12 hours.

In all tests where long and short day plants were grown under the same conditions and thinned to an equal number per unit area, the greatest plant weight was produced by those grown under long days, as shown by Table 2. This is due to the increased amount of top growth that is produced when plants are grown under long days. In all experiments conducted under different day lengths, plant heights and top growth were decidedly greater under longer days as shown for two tests in Table 2. (See Fig. 1.) This increased top growth is due to the increased length of internodes and is similar to the reproductive type of growth normally produced in the second year of growth. Hubam, the annual variety of sweet clover, also produces this type of growth.

In all tests where plants were grown under normal day lengths, the proportion of roots in the total weight was greater for plants grown at the cooler temperatures, as shown in Table 3. This was due in almost every case to an increase in the root weight as well as a decrease in the top growth under the cooler temperatures. Work by Bushnell (1) on the potato indicates that the reduction in the carbohy-

TABLE 2.—*The effect of length of day on height and total plant weight of Melilotus officinalis.*

Date seeded	Date harvested	Length of day, hrs.		Av. weight per plant, grams		Av. height per plant, inches	
		Long day	Short day	Long day	Short day	Long day	Short day
Aug. 21, 1937	Dec. 20	17	Normal (av. 11)	7.4	3.3	28.0	6.7
Mar. 26, 1939	July 7	17	9	—	—	16.4*	4.3*
June 23, 1939	Nov. 2	17	Normal (av. 13)	12.0	9.6	—	—

*M. alba.

drates that resulted from increased respiration at higher temperatures roughly corresponded to the reduction in tuber growth under these conditions. Since carbohydrates constitute most of the storage

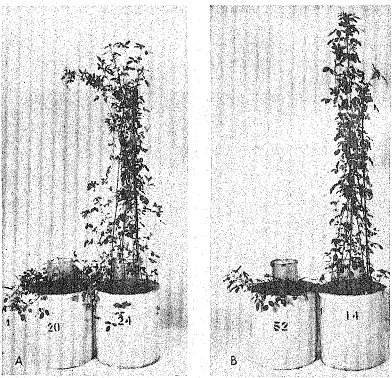


FIG. 1.—Plants of *Melilotus officinalis* seeded on August 21 and harvested December 20, 1937. A, warm temperature; left, normal day length (average 11.0 hours); right, 17-hour day length after October 2. B, cool temperature; left, normal day length (average 11.0 hours); right, 17-hour day length after October 2.

material found in the roots of biennial sweet clover, the rate of respiration would be an important factor in the growth of the roots which act as storage organs when the plant is grown under short days in the fall.

TABLE 3.—*Effect of temperature on the proportion of roots in the total weight and the average weight per plant of sweet clover.*

Seeding date	Harvest date	Average length of day, hrs.	Average mean temperature, °F		Proportion of roots in total weight		Average weight per plant, grams	
			Cool	Warm	Cool, %	Warm, %	Cool	Warm
Aug. 21, 1937	Dec. 20	11.0	71.5	56.0	64.1	49.1	3.3	4.6
June 23, 1939	Aug. 30	14.3	71.8*	82.7*	28.6	18.9	5.0	3.1
June 23, 1939	Nov. 1	13.1	64.0†	71.3†	49.9	38.0	12.8	9.6
Aug. 16, 1939	Nov. 6	12.0	65.2	73.4	57.1	39.1	3.5	3.2

*Only August temperatures were recorded.
†After September 1; all grew at same temperature previous to September.

The total weight per plant varied in different experiments, depending upon the average temperatures and the time when plants were exposed to different average temperatures. Constant temperature differences might possibly show some definite tendencies in total plant weights.

Where plants were grown in the field from June 23 to August 30, those in the drier soil produced a greater proportion of their total weight in the roots than those under moist conditions, as shown by Table 4, but the total weights of the roots plus tops under the two conditions were about the same.

TABLE 4.—*Response of Melilotus officinalis to differences in soil moisture, grown from June 23 to August 30, 1939.*

Water supply*	Proportion of roots in total dry weight, %	Average air-dry yield per acre, lbs.		
		Tops	Roots	Total
Wet..............	18.9	1,420	330	1,750
Dry..............	36.7	1,120	650	1,770

*Wet = ground was saturated to a depth of 12 to 15 inches at least once and often twice weekly; dry = received rainfall only from July 15 to August 30, 2.63 inches.

CHEMICAL ANALYSIS

Increased day length within the limits studied reduced the percentage of total nitrogen in both stems and roots but had no appreciable effect on the nitrogen content of the leaves, as shown by Tables 5 and 6. These lower percentages of nitrogen in the tops and roots of

sweet clover grown under long days correspond to that found in hubam, the annual variety of white sweet clover (10), and in biennial sweet clover during its second year of growth (8, 9, 10).

The higher percentages of nitrogen in the tops (leaves plus stems) of the plants grown under short rather than long days are a result of the higher proportion of leaves. The tops of the short day plants seeded on April 18, 1938, contained 24% leaves, and the tops of the long day plants 19% leaves. Of those seeded on July 16, 46% of the short day tops and 32% of the long day tops were composed of leaves. The higher percentage of nitrogen in the leaves over the stems results in a higher percentage of nitrogen in tops containing a high proportion of leaves.

Under the long days and reproductive type of growth the roots of sweet clover plants approach the appearance and composition of annual roots which are essentially framework and contain little nitrogen. Others (8, 9, 10) have shown that under field conditions, as the days grow longer in the spring and plants go into the reproductive stage, sweet clover contains a lower percentage of nitrogen in the tops and roots.

Tables 5 and 6 indicate that the content of the various carbohydrate and nitrogen fractions of *M. alba* and *M. officinalis* were practically identical for all determinations. These results agree with data of Kirk (2) and Willard (10).

A higher percentage of total carbohydrates was produced in both tops and roots of plants grown under short than under long days, as shown by Tables 5 and 6. Except in one instance, the percentages of all carbohydrate fractions were also greater in plants grown under short days. The smaller percentages of carbohydrates present under long days are possibly due to the abundant production of fiber in the stems. The roots always contained a higher percentage of carbohydrates than the tops regardless of day length. The larger amount of carbohydrates in the roots, especially under short day, was a result of carbohydrate storage. A large percentage of the carbohydrates in the roots of the plants seeded April 18 and July 16, 1938, was starch. Very little starch was present in the roots of the plants seeded August 21, 1937, as shown by Table 5. However, because of a large amount of carbohydrates other than starch, a high percentage of total carbohydrates was present in the roots of these plants, especially those grown under short days.

Winterkilling of sweet clover plants is apparently closely associated with the food materials stored in the roots. Although no winterkilling of normal plants was evident in the winter of 1938–39, almost 100% of the July planting grown under long days in the fall was winterkilled. From an area of 1 square yard which contained 50 to 75 plants of *M. alba*, only 3 plants survived the winter, and from a similar area of *M. officinalis* only 2 lived through the winter. The plants which survived were small, weak, and spindly.

The plants that were winterkilled were lower in nitrogen and carbohydrates, especially starch, in the roots than plants grown under short day lengths in the fall, as shown in Tables 5 and 6. In addition to the lower percentage of starch and nitrogen in the roots of the plants

TABLE 5.—*Nitrogen and carbohydrate fractions in Melilotus officinalis on dry weight basis, 1937 and 1938.*

Date seeded	Date harvested	Length of day, hours	Portion of plant	Soluble nitrogen, %	Non-soluble nitrogen, %	Total nitrogen, %	Total sugars, %	Starch, %	Polysaccharides, %*	Total carbohydrates, %
				1937						
Aug. 21	Dec. 20	11.0†	Tops	0.39	2.82	3.21	1.3	0.6	8.5	9.8
			Roots	0.44	2.69	3.13	5.5	2.4	38.8	44.3
Aug. 21	Dec. 20	17.0	Tops	0.40	1.72	2.12	1.3	Trace	6.0	7.3
			Roots	0.51	1.50	2.01	13.0	1.1	19.4	32.4
				1938						
Apr. 18	July 7	14.4†	Tops	0.48	2.64	3.12	4.0	4.6	20.4	24.4
			Roots	1.04	1.56	2.60	3.7	20.3	37.9	41.6
Apr. 18	Oct. 23	13.3†	Leaves	0.51	3.82	4.33	6.3	5.7	13.9	20.2
			Stems	0.36	1.37	1.73	6.2	3.3	20.6	26.8
			Tops	0.39	1.96	2.35	6.2	3.9	19.0	25.2
			Roots	1.18	1.92	3.10	6.8	36.1	50.9	57.7
Apr. 18	Oct. 23	16.0‡	Leaves	0.77	3.81	4.58	4.9	5.0	13.0	17.9
			Stems	0.34	1.28	1.62	1.6	2.9	19.4	21.1
			Tops	0.43	1.76	2.19	2.3	3.3	18.2	20.5
			Roots	1.12	1.34	2.46	10.9	19.6	37.6	48.5
July 16	Oct. 23	12.6†	Leaves	0.43	4.09	4.52	7.4	6.7	15.4	22.8
			Stems	0.40	1.47	1.87	6.7	3.9	18.6	25.3
			Tops	0.42	2.74	3.16	7.0	5.2	17.1	24.1
			Roots	1.42	2.07	3.49	6.7	30.4	44.9	51.6
July 16	Oct. 23	16.0‡	Leaves	0.43	4.04	4.47	5.8	5.7	13.8	19.6
			Stems	0.33	1.19	1.52	3.4	2.6	19.1	22.5
			Tops	0.36	2.09	2.45	4.1	3.6	17.4	21.5
			Roots	0.58	1.06	1.64	2.8	11.9	24.4	27.2

*Includes starch.
†Average of normal day length.
‡After August 2.

TABLE 6.—*Nitrogen and carbohydrate fractions in Melilotus alba on dry weight basis, 1938.*

Date seeded	Date harvested	Length of day, hours	Portion of plant	Nitrogen			Carbohydrates			
				Soluble nitrogen, %	Nonsoluble nitrogen, %	Total nitrogen, %	Total sugars, %	Starch, %	Polysaccharides, %*	Total carbohydrates, %
Apr. 18	Oct. 23	13.3†	Leaves	0.46	4.04	4.50	5.0	4.4	13.9	18.9
			Stems	0.34	1.16	1.50	7.5	3.0	20.5	28.0
			Tops	0.37	1.88	2.25	6.8	3.4	18.9	25.7
			Roots	1.20	2.22	3.42	7.1	24.5	45.0	52.1
Apt. 18	Oct. 23	16.0‡	Leaves	0.46	3.98	4.44	6.1	4.0	14.4	20.5
			Stems	0.37	0.99	1.36	3.9	1.5	19.0	22.9
			Tops	0.39	1.59	1.98	4.4	2.0	18.1	22.4
			Roots	1.08	1.69	2.77	5.5	18.3	36.4	41.9
July 16	Oct. 23	12.6†	Leaves	0.56	4.31	4.87	4.9	3.6	11.8	16.7
			Stems	0.53	1.59	2.12	7.5	2.9	19.0	26.5
			Tops	0.55	2.97	3.52	6.2	3.3	15.4	21.6
			Roots	1.40	2.41	3.81	6.3	33.2	44.1	50.4
July 16	Oct. 23	16.0‡	Leaves	0.47	3.98	4.45	6.7	6.1	15.5	22.2
			Stems	0.30	1.04	1.34	5.8	2.2	20.4	26.2
			Tops	0.36	2.14	2.50	6.1	4.1	18.6	24.7
			Roots	1.03	1.37	2.40	4.8	11.3	26.3	31.1

*Includes starch.
†Average of normal day length.
‡After August 2.

grown under long days, the plants also had much smaller, nonstorage type of roots similar to the roots of Hubam, the annual variety of white sweet clover.

BLOOMING AND CROWN BUDS

Biennial sweet clover does not ordinarily bloom the seeding year under Ohio conditions. Over 50% of the plants seeded August 21, 1937, that were grown in the greenhouse under long day (17-hour day length) and warm temperature (average 71.5°F) were in bloom by December 20, while only 25% of the plants under cool temperature (average 56.0°F) had started to bloom. The cooler temperatures definitely delayed the flowering dates. In both warm and cool sections all plants that grew throughout the winter ultimately bloomed. However, the plants under warm temperatures always developed faster than those at the cool temperatures.

Over 19% of the plants of *M. alba* and 14% of the *M. officinalis* plants seeded in the field March 26, 1939, which had grown under a 17-hour day length were in bloom by June 27, or at three months of age. In all tests where plants were grown under long days and for a sufficient time the plants bloomed.

Under field conditions in Ohio each plant of biennial sweet clover produces several crown buds at the base of the stem during the fall of the seeding year (10). Except in a few instances, these crown buds never start growth in the fall. They grow the following spring and are the only shoots which sweet clover produces from the crown.

Whenever plants were exposed to a 16- or 17-hour day length, either in the field or when grown in pots in the greenhouse, never more than two crown buds set on a plant, and there was only one or even none in many instances. Occasionally, these crown buds started growing like the branches higher up on the stem. Plants growing in pots under normal, short-day length in the late fall produced from 2 to 12 buds on every plant with an average of 7 to 8. This production of several crown buds under short day and few or none under long day is associated with storage in the roots. Each plant with several crown buds has a large storage type of root.

As long as the plants remained under short days, both the stem internodes and crown buds failed to elongate. When placed under long days, the stem internodes always elongated, but the crown buds did not always produce shoots at this time. However, if the original stem was cut off or injured sufficiently, the crown buds on plants under long days immediately increased in height, but they never elongated under a 9- to 12-hour day length. The presence of the original stem or a part of this stem was responsible for restriction of the growth of shoots from the crown buds under long days. Removal of the original stem then allowed the crown bud internodes to increase in length. No other factors which could cause the crown buds to start growth immediately after formation were determined. The short days kept the buds from producing any visible growth even though the main stem was removed.

In 1937, 1938, and 1939 sweet clover plants that were grown in the greenhouse from summer or fall to spring and then transplanted into

the field lived for more than two years (three summers in some instances) and produced from two to three sets of crown buds. The first set of crown buds was produced on the August 21, 1937, seeding of *M. officinalis* in the fall and early winter, and shoots from these buds bloomed in most cases by May, 1938. The main stem on all plants grown under a 17-hour day length had bloomed during the fall and winter. After the main stem died and was removed, shoots from the crown buds grew and bloomed in the spring. Where plants were grown under short day lengths, only the main stem bloomed in the spring. When some of these plants from long days were transplanted to the field, they immediately produced a second set of crown buds and these buds grew into shoots that were 15 to 20 inches in height by fall. A third set of crown buds was produced in the fall and these grew and bloomed normally in the spring of 1939. Plants from the short-day group when transferred to the field produced shoots from the original crown buds the first summer. A second set of crown buds was produced in the fall rather than a third set as had been produced from the plants that had been under long days when in the greenhouse. The results from the 1938 and 1939 seedings duplicated the above results.

This apparent production of a perennial out of a biennial plant seems to be due to keeping the plants under nonfreezing temperatures. Once the plants were exposed to a normal winter, they died after blooming. How long the plants would live if not exposed to freezing temperatures was not determined.

SUMMARY

Two species of biennial sweet clover, *Melilotus alba* and *M. officinalis*, were grown under varying conditions of temperature, moisture, and length of exposure to daylight both in the field and in pots in the greenhouse. Data are presented showing the effect of length of day on root-top ratios, total weight of roots and tops, height of plants, blooming, crown buds, and the carbohydrate and nitrogen content in the roots and tops. Limited observations on the effect of soil moisture supply on root and top growth and the effect of temperature variations on root and top growth, blooming, and crown buds are also included.

In all cases where sweet clover was grown under different day lengths the shorter the day length, within the limits studied, the greater the proportion of the total plant weight in the roots of both *M. alba* and *M. officinalis*. In a typical experiment the percentage of the total weight in the roots was 11.8 under a 17-hour day and 64.1 under normal fall day lengths (average 11.0 hours). However, the greatest total plant weight was produced by plants grown under long-day lengths provided other conditions were the same.

Plant heights were always increased under longer day lengths. This was largely due to increased length of the internodes.

Biennial sweet clover does not ordinarily bloom in the seeding year under Ohio conditions. Under 17-hour day lengths, plants of both

yellow and white sweet clover planted in the field bloomed within three months after seeding. Low temperatures always retarded flowering.

Increased day length always restricted crown bud formation. Day lengths of 16 or 17 hours limited crown bud formation to a maximum of two per plant, many plants producing none under these conditions. Under normal short-day lengths in the fall or winter, from 2 to 12 (average 7 to 8) crown buds were produced on each plant.

All crown buds on plants growing under long days immediately grew into shoots if the main stem was cut off or severely injured, and sometimes without stem injury. Under short days, crown buds remained "dormant" and did not elongate, even if the top was cut off.

By growing plants in the greenhouse during the winter and then transferring them to the field in the early spring plants lived for three summers and produced three sets of crown buds, whereas under normal conditions in the field sweet clover is strictly a biennial and produces one set of crown buds which bloom in the spring of the second year of growth. In most cases flowers were produced on the original stem as well as on shoots developed from each set of crown buds.

Plants grown in the field under low moisture supply produced a higher proportion of their total weight in the roots than did plants grown under high moisture supply, but the total weights of the roots plus the tops under the two conditions were about the same.

Plants grown under cool temperatures always produced a larger proportion of their total plant weight in the roots than did plants grown under warmer temperatures.

Plants grown under day lengths of 16 and 17 hours produced a lower percentage of total nitrogen in both the stems and roots than did plants grown under day lengths of 10 to 13 hours. Day length had little effect in altering the nitrogen content of the leaves.

A higher percentage of total carbohydrates was present in both tops (stems and leaves) and roots of plants grown under short than under long day lengths. The roots of sweet clover plants always contained a higher percentage of carbohydrates than the tops regardless of day length.

Melilotus alba and *M. officinalis* were very similar in content of nitrogen, total sugars, starch, polysaccharides, and total carbohydrates.

Although no winterkilling of normal plants was evident in the winter of 1938–39, almost 100% of the July planting that was grown under a 16-hour day length in the fall was winterkilled. Plants under long-day length not only had nonstorage type of roots but also contained a much smaller percentage of carbohydrates, especially starch, in the roots than did plants grown under the normal short-day lengths in the fall.

LITERATURE CITED

1. BUSHNELL, J. The relation of temperature to growth and respiration in the potato plant. Minn. Agr. Exp. Sta. Tech. Bul. 34. 1925.
2. KIRK, L. E. A comparison of sweet clover types with respect to coumarin content, nutritive value and leaf percentage. Jour. Amer. Soc. Agron., 18: 385–392. 1926.

3. MARTIN, J. N. The relative growth and interdependence of tops and roots of the biennial white sweet clover, *Melilotus alba* Desr. Amer. Jour. Bot., 21: 140–159. 1934.
4. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. Washington: Assoc. Off. Agr. Chemists. Ed. 3. 1930.
5. PIETERS, A. J. Difference in internode lengths between, and effect of variations in light duration upon, seedlings of annual and biennial sweet clover. Jour. Agr. Res., 31:585–596. 1925.
6. ROBERTS, R. H., and STRUCKMEYER, B. ESTHER. The effect of temperature and other environmental factors upon the photoperiodic responses of some of the higher plants. Jour. Agr. Res., 56:633–678. 1938.
7. SHAEFFER, P. A., and HARTMAN, A. F. The iodometric determination of copper and its use in sugar analysis. Jour. Biol. Chem., 45:349–390. 1921.
8. SNIDER, H. J., and HEIN, M. A. The nitrogen and dry matter content of sweet clover tops and roots at various stages of growth. Jour. Amer. Soc. Agron., 18:273–280. 1926.
9. WHITING, A. L., and RICHMOND, T. E. The composition of biennial white sweet clover as related to soil enrichment. Soil Sci., 22:83–94. 1926.
10. WILLARD, C. J. An experimental study of sweet clover. Ohio Agr. Exp. Sta. Bul. 405. 1927.

GREEN AND AIR-DRY WEIGHTS FOR DETERMINING HAY YIELDS OF VARIETIES OF ALFALFA[1]

RALPH M. WEIHING[2]

THE most rapid and accurate methods in harvesting plots and in computing yields are desired in conducting experiments with alfalfa. The practice of computing the forage yield of alfalfa from green weights is rapid but is accurate only when there are no differences in the percentage dry matter between plots. Procedures in which it is assumed that all strains, treatments, replications, or plots contain the same percentage of dry matter decrease in precision with increases in differences between the above-listed variables. At times it may seem expedient to report forage yields of alfalfa as air-dry hay.[3] The accuracy of this method is dependent largely upon the variability, if any, of the strains in dry matter content when air-dry.

The experiments presented were designed to ascertain the differences of a number of strains and varieties of alfalfa in percentage dry matter of (a) the green forage and (b) the air-dry forage.

LITERATURE

Investigators differ in opinion as to the accuracy of green weights in determining the yield of forage plants. Arny (1),[4] McKee (2), McRostie and Hamilton (3), and Vinall and McKee (5) point out that forage yields based on green weights are not very reliable. Wilkins and Hyland (7) conducted experiments with several varieties of alfalfa and with several varieties of red clover and reported that "yield determinations would have been essentially as accurate on a green weight basis without sampling." Wilkins and Westover (8) found the difference in moisture content of Grimm and Turkestan alfalfa so slight that yield data may be based on green weights.

The following investigators agree that accurate results are obtained by reducing field weights of green or field-cured forage to air-dryness: Arny (1), McKee (2), and Vinall and McKee (5).

EXPERIMENTAL TECHNIC

The percentage dry matter in the green and the air-dry forage was determined for Grimm, Hardistan, Nebraska Common, Meeker Baltic, and Ladak varieties of alfalfa grown in the following five types of nursery plots: Single rows 3 feet apart; single rows 20 inches apart; three-row plots with rows 20 inches apart and 20-inch alleys; three-row plots with rows 12 inches apart and 20-inch alleys; five row plots with rows 12 inches apart and 20-inch alleys. These plots are described more fully by Weihing and Robertson (6).

[1]Contribution from Agronomy Section, Colorado Experiment Station, Fort Collins, Colo. Published with the approval of the Director of the Colorado Experiment Station as Scientific Series Paper No. 143. Received for publication May 4, 1942.

[2]Assistant Agronomist.

[3]Dried for several weeks in the air under cover for protection from inclement weather.

[4]Figures in parenthesis refer to "Literature Cited", p. 881.

The plots of each type were arranged in a Latin square. The center 16 feet of the 18-foot plots was used for forage determinations. The plots were seeded in 1938 and harvested once in 1938 and three times in 1939. In 1938, all rows of each plot were used in the dry matter determinations, but in 1939 only the center row of the multiple-row plots was used.

The percentage of dry matter in the green and air-dry forage for 55 strains and varieties of the U. S. Department of Agriculture Uniform Alfalfa Nursery seeded in 1937 was determined for the third cutting in 1938 and the three cuttings in 1939. The center 16 feet was harvested from the 18-foot plots (single rows 3 feet apart). Duplicate plots (two replications) of each strain or variety were available in this experiment.

In all cases the data were analyzed by the variance method to determine the statistical significance of differences in the percentage dry matter in the green and in the air-dry forage of the various varieties and strains. The test of significance was made by computing F values (4); that is, variety variance/error variance.

The plots were weighed green as soon as cut, field-cured enough before putting into cloth sacks to prevent spoilage, uniformly air-dried in an open shed, and weighed air-dry several weeks after storage. After weighing, the air-dry samples were ground in a "Wiley mill" and a representative 10-gram sample of each dried in an oven. The computation for percentage dry matter in air-dry samples was $\frac{\text{oven-dry weight of sample}}{10} \times 100$. The percentage dry matter in the green forage was computed as follows: $\frac{\text{air-dry weight of plot}}{\text{green weight of plot}} \times$ per cent dry matter in the air-dry forage. All of the green weights and all of the air-dry weights for each experiment were taken within one day to minimize changes in moisture content caused by variations in weather conditions.

PERCENTAGE DRY MATTER IN GREEN FORAGE

The data for percentage dry matter in the green forage in Tables 1 and 2 show that some varieties differ significantly in this respect. For the experiment with five varieties (Table 1) the difference between the highest and lowest percentage expressed in per cent of the 25-plot average for each cutting was 3.52, 3.86, 3.81, and 6.44 for the one cutting in 1938 and the first, second, and third cuttings in 1939, respectively. A similar analysis of the data for the 55-strain experiment shows that the extreme differences in percentage of the 2-plot average were 19.21 to 34.24.

The different types of plots also show a difference in moisture content of the five varieties tested, indicating that yields based on green weights show significant differences between varieties for all types of plots except for the five-row plots with rows 12 inches apart. These data indicate that varieties of alfalfa cut on the same day may contain different amounts of moisture in the green forage and that serious inaccuracies can arise by estimating dry yields from the green weights of alfalfa plots.

The percentage dry matter in the green forage was found to vary between replications of the same experiment (Table 3). Significant differences were found in 12 of the 19 sets of data examined.

TABLE 1.—*Variations in the percentage of dry matter in the green and in the air-dry forage for five varieties of alfalfa grown in five types of plots harvested in 1938 and 1939.*

Type of plot	1938 cutting		1939 cuttings					
			1st		2nd		3rd	
	E†	D	E	D	E	D	E	D
Green Forage								
Single rows 3 feet apart	0.70	7.66*	1.93	4.36	0.18	6.41**	1.97	8.26
Single rows 20 in. apart	0.43	6.21*	0.60	3.49	0.26	4.99*	—	—
3 rows 20 in. apart	1.51	2.43	2.35	9.35	0.38	5.59	0.26	9.57**
3 rows 12 in. apart	2.07	3.92	0.30	7.11**	0.14	3.76*	0.31	7.92**
5 rows 12 in. apart	3.06	5.02	1.82	4.62	0.78	3.66	0.76	5.91
25 plots all types	1.55	3.52**	1.42	3.86	0.35	3.81**	0.39	6.44**
Air-Dry Forage								
Single rows 3 feet apart	0.43	0.38	0.050	0.05	0.034	0.26	0.078	0.36
Single rows 20 in. apart	0.10	0.65	0.028	0.15	0.066	0.24	—	—
3 rows 20 in. apart	0.346	0.32	0.098	0.24	0.132	0.43	0.120	0.21
3 rows 12 in. apart	0.189	0.26	0.050	2.21	0.073	0.17	0.150	0.21
5 rows 12 in. apart	0.105	0.66	0.045	0.53*	0.060	0.50	0.045	0.26
25 plots all types	0.23	0.17	0.055	0.12	0.076	0.11	0.098	0.21

†E = Error variance. $D = \frac{\text{range} \times 100}{\text{average}}$.

Single and double star if F exceeds 5% and 1% levels, respectively.

TABLE 2.—*Variations in the percentage of dry matter in the green and in the air-dry forage for 55 strains of alfalfa harvested in 1938 and 1939.*

	Green forage				Air-dry forage			
	1938, 3rd cutting	1939 cuttings			1938, cutting	1939 cuttings		
		1st	2nd	3rd		1st	2nd	3rd
Difference (highest-lowest strain)	4.50	6.90	5.25	5.00	1.55	0.55	1.55	0.75
(Difference/average) 100	19.21	34.24	22.24	19.97	1.68	0.59	1.68	0.82
F values (variety/error variance)	1.99*	0.98	2.03*	1.15	1.88*	1.71*	3.21†	0.74

*Greater than 5% point.
†Greater than 1% point.

PERCENTAGE DRY MATTER IN AIR-DRIED FORAGE

The varieties in the five-variety experiment (Table 1) contained so nearly the same amount of dry matter when air-dry that significant

differences were not detected, except in the first cutting for the five-row plots. In three of the four cuttings studied of the 55-strain experiment (Table 2) significant differences were found. However, the greatest errors were only 1.68, 0.59, 1.68, and 0.82% for the third cutting in 1938 and the first, second, and third cuttings in 1939, respectively.

TABLE 3.—*F values (block variance/error variance) to determine the significance of differences in percentage dry matter of the green forage between the replications of an experiment with five replications and five varieties for each of five types of plots.*

Types of plots	1938 cutting	1939 cuttings		
		1st	2nd	3rd
Single rows, 3 feet apart	1.46	3.69*	5.01*	0.42
Single rows, 20 in. apart	10.53†	1.18	13.25†	—
3-rows, 20-in. rows, 20-in. alleys	2.95	0.46	3.82*	2.89
3-rows, 12-in. rows, 20-in. alleys	14.68†	2.48	27.80†	6.74†
5-rows, 12-in. rows, 20-in. alleys	4.20*	8.29†	10.39†	5.03*

*Greater than 5% point.
†Greater than 1% point.

DISCUSSION

The acre yield of alfalfa in variety and strain experiments often is reported in pounds or tons of oven-dry forage, or of forage containing a definite amount of moisture such as 12%. The yield of oven-dry forage may be obtained by oven drying the forage of each plot as is possible with small plots with rows 1 rod long. With large plots it is obtained by reducing field weights of green or field-cured forage to oven dryness from data secured on samples drawn at the time of weighing. Proper procedures in ascertaining oven-dry yields result in very accurate data. However, in some instances the plots of experiments with several to many strains of alfalfa are weighed green and the oven-dry plot yields computed from the average percentage dry matter of a few random samples taken during the period of harvest and without regard to the sampling of each variety. This method results in serious errors as strains and replications may vary in percentage dry matter at any one date of cutting. While the green weight method of determining forage yields most often is used in experiments of many strains and few replications, the data presented show that the errors of the green weight method are much higher for such experiments than they are for those with few varieties and many replications. The field weights of green forage of each variety should be reduced to oven-dryness or some other standard with adequate data obtained from sampling each variety. The safe procedure is to sample each plot.

The data presented show that the varieties and strains of alfalfa examined had about the same percentage dry matter within cuttings after thoroughly drying in the air under cover. This indicates that air-dry yields of varieties are comparable within cuttings. However,

some error will occur when different cuttings are compared or when different years are compared. If comparisons between cuttings or between years are wanted, the forage yield should be computed to oven dryness or a definite dry matter content such as 88%. This can be done by oven drying an adequate air-dry sample from each cutting of the experiment without regard to variety.

SUMMARY

The percentage dry matter in a number of varieties of alfalfa was determined in the green forage and in the forage air dried under cover. The number of varieties or strains was 5 in one experiment and 55 in the other. There were 25 plots of each variety in the former and 2 in the latter. All varieties were grown in nursery plots. Data are reported on four cuttings; one in 1938 and three in 1939.

The data show that some varieties and replications differ in percentage dry matter at the time of cutting and that the percentage dry matter in samples air dried under cover for several weeks was nearly equal in all varieties. In the experiment of five varieties the average maximum differences in dry matter between two varieties for the three cuttings in 1939 decreased as the number of replications increased. The lowest difference was found when 25 replications were used. In the experiment of the 55 strains, average maximum differences in dry matter between 2 varieties were much greater than those found where only 5 varieties with a greater number of replications were used. The dry matter differences in the air-dry samples were in the same order but were much smaller and not significant.

CONCLUSIONS

The percentage dry matter in green alfalfa varies sufficiently between some varieties at the time of cutting to make forage yields based on green weights inaccurate. Green weights should be reduced by plots to oven dryness, to an exact percentage of dry matter, or to air dryness. Forage yields of alfalfa varieties based on samples or plots air dried under cover are nearly as accurate as those based on oven-dry weights. For comparisons between cuttings or between years, air-dry forage yields should be reduced to a definite percentage of dry matter.

LITERATURE CITED

1. ARNY, A. C. The dry matter content of field-cured and green forage. Jour. Amer. Soc. Agron., 8:358–363. 1916.
2. MCKEE, ROLAND. Moisture as a factor of error in determining forage yields. Jour. Amer. Soc. Agron., 6:113–117. 1913.
3. MCROSTIE, G. P., and HAMILTON, R. I. Accurate determination of dry matter in forage crops. Jour. Amer. Soc. Agron., 19:243–251. 1927.
4. SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934.
5. VINALL, H. N., and MCKEE, ROLAND. Moisture content and shrinkage of forage and the relation of these factors to the accuracy of experimental data. U.S.D.A. Bul. 353. 1916.

6. WEIHING, RALPH M., and ROBERTSON, D. W. Forage yields of five varieties of alfalfa grown in nursery rows and field plots. Jour. Amer. Soc. Agron., 33: 156–163. 1941.
7. WILKINS, F. S., and HYLAND, H. L. The significance and technique of dry matter determinations in yield tests of alfalfa and red clover. Iowa Agr. Exp. Sta. Res. Bul. 240. 1938.
8. ————, and WESTOVER, H. L. Turkestan alfalfa as compared with Grimm for wilt-infected soils in Iowa. Jour. Amer. Soc. Agron., 26:213–222. 1934.

NOMOGRAMS FOR RAPID CALCULATION OF SOIL DENSITY, WATER CONTENT, AND TOTAL POROSITY RELATIONSHIPS[1]

G. B. Bodman[2]

CALCULATIONS having immediate practical utility in applied soil physics may be quickly made if attention is given to the development of the most direct expressions relating the soil properties concerned. Charts and tables may then be prepared to cover the most important ranges so that the desired results may be seen at a glance. Examples are to be found in the nomograms which have been prepared for aid in mechanical analysis calculations (3, 6)[3] for a variety of experimental conditions, in tables compiled for use in irrigation practice (4), and in nomograms indicating the probable relations between certain soil properties and the most suitable spacing of tile for soil drainage (5).

It is recognized that numerical values estimated from graphs are seldom so accurate as those obtained by direct calculation, or from carefully prepared tables. Graphs usually have the advantage, however, of presenting in a given space values covering wider ranges of relationships than tables. Moreover, the accuracy obtainable is frequently adequate, particularly when the nature of the problem and the available measurements themselves preclude a high degree of exactness. But neither diagrams nor tables are any more reliable than the equations from which they are derived. It is important, therefore, that any basic assumptions which may have been made in the calculations be clearly understood by the user.

The diagrams which are presented here are designed to facilitate certain calculations involving some of the most simple and elementary properties of the soil, particularly in relation to water content and well-established empirical observations concerning penetration. They are based upon alignment charts (2) which for several years have been found useful for instructional purposes and which have also been used in laboratory and field practice. The relationships discussed are in common use in western United States, but they may be frequently used to advantage wherever irrigation, drainage, watershed management, soil conservation practices, and other soil and water relations are under consideration.

EQUATIONS AND NOMOGRAM FOR SOIL AND WATER, VOLUME AND WEIGHT RELATIONS

The equation for the conversion of an amount of soil water from a mass to a volume ratio is given by

$$\frac{v_L}{v_S+v_L+v_G}=\frac{m\ .\ s_A\ .\ \rho_L}{\rho'_L} \qquad \text{I}$$

[1]Contribution from the Division of Soils, University of California, Berkeley, Calif. Received for publication June 1, 1942.

[2]Professor of Soil Physics.

[3]Figures in parenthesis refer to "Literature Cited", p. 892.

which, if $\rho'_L = \rho_L$, becomes

$$\frac{v_L}{v_A} = m \cdot s_A \qquad 2$$

in which

v_L = volume of liquid in soil (soil water)
v_S = volume of solid (inorganic and organic soil particles)
v_G = volume of gas (soil air)
v_A = $v_S + v_L + v_G$ = apparent volume of undisturbed soil
m = mass of water per unit mass of soil, after drying at 105°C
s_A = apparent specific gravity of undisturbed soil
ρ_L = absolute density of water in bulk
ρ'_L = absolute density of water in soil

The equation takes no account of soil water which is not removed at 105°C and assumes that all losses in weight at this temperature are due to the removal of soil water. In the final form 2 of the equation it is further assumed that no difference exists between the absolute density of water in bulk and that of water dispersed, by numerous forces, throughout the porous body of soil and removable at the conventional temperature. This assumption may not be permissible in certain calculations, particularly when dealing with that fraction of the soil water which is most closely associated with the solid phase. It is probable, however, that for field soil calculations the error introduced is of little consequence in comparison with those errors which persist owing to soil heterogeneity, even in what appears to be a field of uniform soil of a single soil type.

It will be observed that the ratios included in equation 1 are dimensionless. Provided that like dimensions are expressed in units of the same system of measurement, therefore, the ratios are independent of the units used. In practice the following substitutions are commonly made:

$$\text{(i)}\ \frac{v_L}{v_A} = \frac{d}{D},$$

$$\text{(ii)}\ m = \frac{P_w}{100}$$

in which, in addition to those symbols which have already been defined, d and D, given in the same units of length, are the corresponding depths of water and unaltered soil, respectively, per unit cross-sectional area of a vertical column of unaltered soil, and P_w equals the grams of water present per 100 grams of dry soil, or the percentage water content by weight.

The ratio d/D in (i) may be easily visualized by considering the result of extracting all water which is removable at 105°C from a vertical column of soil, *in situ*, and collecting the water in a vertical-walled vessel of the same internal cross section as the cross section of the soil column. The depth of water, d, in the vessel may then be compared with the depth of soil, D, from which it was obtained. It should be pointed out that for many calculations in irrigation and

drainage practice it is assumed that the removal of water from, and its addition to, the soil is without significant effect upon the apparent volume of the soil. Whereas this is probably substantially true for subsoils and at all depths in many sandy soils, it is certainly not true for all surface soils, highly organic soils, clays, or others which shrink and swell when dried or wetted. Evidently the greater the depth of soil under consideration and the less the volume change which it undergoes with changes in water content, the less is the error.

Since when measuring the mass of a given volume of soil *in situ* it is usually the apparent density, ρ_A, in grams per cc which is actually determined and reported, and in the C.G.S. system the absolute density of water may be regarded as unity, the apparent density may conveniently replace the apparent specific gravity in equation 1 with no loss in accuracy.[4] If the apparent density of the undisturbed soil has been measured in pounds per cubic foot it must, of course, be converted to apparent specific gravity (a dimensionless value) by dividing by the mass of 1 cubic foot of water, except when graphical provision has already been made for this transformation in nomograms and charts.

Equation 1 then assumes the form which is so widely used in irrigation practice,

$$\frac{d}{D} = \frac{P_w}{100} \cdot s_A \qquad 3$$

Evidently if three of the four possible variables in this equation are known, the fourth may be calculated. The number of variables may be most conveniently reduced to three by letting D equal unit depth of soil.

Equation 3 may be represented graphically by a solid, such as is drawn isometrically in Fig. 1. In this solid all possible magnitudes of d, when $D = 1$, are given by the slightly curved, sloping surface facing the observer, for $0 < P_w < 63\%$ and $1.00 < s_A < 1.75$. The magnitude of d per unit depth of soil is obtained from the height on the sloping surface of a point lying vertically above the point on the base which has the proper moisture content and apparent specific gravity coordinates. The broken lines on the surface indicate the positions of water depth, d, contours by intervals of one-tenth. The crest of the solid, where the vertical back (hidden from view) and sloping surface intersect, is defined by limitations imposed by the porosity of the soil upon its water-retentive capacity. Evidently, if the density of water remains unchanged upon entry into the soil, i.e., if the water is strictly incompressible, the maximum limiting volume (measured before being added to the soil) which can be retained cannot exceed the total pore volume. The actual volume of water retained after free drainage depends in general upon soil properties other than the gross porosity. In Fig. 1 the limiting porosities corresponding to different values of apparent density have been arbitrarily set by choosing a real density of 2.70 grams/cm³, but the soil real density does not in any other

[4]For this reason the term apparent density is used in Fig. 2 (nomogram 1, right hand scales, B_1 and B_2).

respect affect the form of the solid figure, nor are the scale graduations affected.

Numerous experiments have shown that upon addition of water to a water-permeable soil and the maintenance at the soil surface, during the addition, of a constant energy level per gram of water, infiltration is at first very rapid and later proceeds more slowly. When surface addition of water has ceased, downward penetration of water into deeper layers of soil continues under isothermal conditions, but at a rate which diminishes over a long time period. The rate of penetration

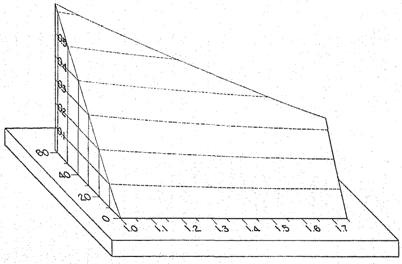


FIG. 1.—Isometric drawing of solid, representing interrelationships of soil properties designated by coordinates. Coordinates: Front, apparent specific gravity of soil, or apparent density in C. G. S. units; side, water content, percentage by weight, dry basis; vertical, depth, or volume, ratio of water to soil.

soon becomes so small that it may be neglected for many practical purposes, particularly by comparison with the rate of water loss due to transpiration. It has been repeatedly found that the average soil moisture content behind the advancing water front has, at the time of the practical cessation of downward movement, a magnitude characteristic of the soil at the time of the experiment. This moisture content is often called the field capacity. It must be measured in the soil during the exclusion of transpiration and evaporation losses when it may be concisely defined as that moisture content at which, on the moisture content-time graph $\Delta P_w/\Delta t$ begins to approach very closely to zero. Less time appears to be required for the soil to reach its field capacity when relatively dry soil is present beyond the wetting front than is the case when the soil is initially fairly moist to a considerable depth. The phenomenon is most strikingly demonstrated during the entrance of water into a texturally uniform, fairly dry

soil column. For soils of intermediate texture the field capacity has been shown by numerous investigators to be approximately equal to the moisture equivalent.

The conception of a field capacity has long been used in irrigation and related practice by the adaptation of equation 3 to the calculation of the requisite amount of water for increasing the water content of the soil from some initial water content, P_I, to the field capacity, P_{FC}, thus:

$$d = \frac{(P_{FC}-P_I) \; . \; s_A \; . \; D}{100}.$$

Equation 3 may be used for various purposes. Its common uses are described in Table 1.

Although the solid represented in Fig. 1 has certain special advantages[5] for indicating the relationships existing between depth of water retained per foot of soil, the weight percentage present, and the soil apparent specific gravity, in its present form it does not permit the actual numerical values for d to be very readily obtained. Numerous methods of graphing these relationships on a single plane for practical use readily suggest themselves, but probably the most useful representation is that given by a nomogram of the third class (1) consisting of three parallel straight lines. It is not difficult to construct or read and permits easy, direct interpolation between scale graduations during its use. Fig. 2 is a nomogram which has been prepared, like Fig. 1, from equation 3 by letting $D = 1$, whereupon

$$\log \frac{P_w}{100} + \log s_a - \log d = 0 \qquad 4$$

Calculations by means of the nomogram are made in the usual way. A straight edge, preferably a thin, transparent strip of celluloid upon the lower face of which is lightly engraved a straight line, is placed on the nomogram so that the straight line intersects known values on two of the graduated scale lines after which the third, desired value may be read at the point of intersection of line and third scale line.

Different uses of this nomogram are listed in Table 1. When using the nomogram, it must be recalled that if values of d are required corresponding to soil depths greater than $D = 1$, the d values read off the nomogram must be multiplied by the actual depth of soil.

EQUATIONS AND NOMOGRAM FOR RELATIONS BETWEEN SOIL DENSITIES AND TOTAL POROSITY

The total porosity, E, of the soil, defined as the ratio of the sum of the volumes of the nonsolid phases to the sum of the volumes of

[5]Since d = a depth, this fact is rather readily suggested by a vertical distance. When D = 1 foot, and a body of soil 1 square foot in cross section is considered, d represents the quantity of water, as a fraction of a cubic foot, present in 1 cubic foot of soil.

respect affect the form of the solid figure, nor are the scale graduations affected.

Numerous experiments have shown that upon addition of water to a water-permeable soil and the maintenance at the soil surface, during the addition, of a constant energy level per gram of water, infiltration is at first very rapid and later proceeds more slowly. When surface addition of water has ceased, downward penetration of water into deeper layers of soil continues under isothermal conditions, but at a rate which diminishes over a long time period. The rate of penetration

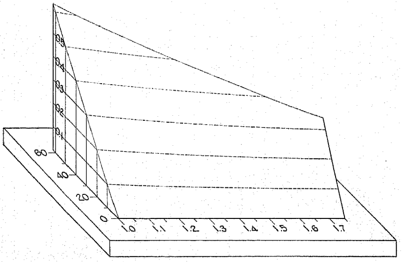


FIG. 1.—Isometric drawing of solid, representing interrelationships of soil properties designated by coordinates. Coordinates: Front, apparent specific gravity of soil, or apparent density in C. G. S. units; side, water content, percentage by weight, dry basis; vertical, depth, or volume, ratio of water to soil.

soon becomes so small that it may be neglected for many practical purposes, particularly by comparison with the rate of water loss due to transpiration. It has been repeatedly found that the average soil moisture content behind the advancing water front has, at the time of the practical cessation of downward movement, a magnitude characteristic of the soil at the time of the experiment. This moisture content is often called the field capacity. It must be measured in the soil during the exclusion of transpiration and evaporation losses when it may be concisely defined as that moisture content at which, on the moisture content-time graph $\triangle P_w/\triangle t$ begins to approach very closely to zero. Less time appears to be required for the soil to reach its field capacity when relatively dry soil is present beyond the wetting front than is the case when the soil is initially fairly moist to a considerable depth. The phenomenon is most strikingly demonstrated during the entrance of water into a texturally uniform, fairly dry

soil column. For soils of intermediate texture the field capacity has been shown by numerous investigators to be approximately equal to the moisture equivalent.

The conception of a field capacity has long been used in irrigation and related practice by the adaptation of equation 3 to the calculation of the requisite amount of water for increasing the water content of the soil from some initial water content, P_I, to the field capacity, P_{FC}, thus:

$$d = \frac{(P_{FC}-P_I) \,.\, s_A \,.\, D}{100}.$$

Equation 3 may be used for various purposes. Its common uses are described in Table 1.

Although the solid represented in Fig. 1 has certain special advantages[5] for indicating the relationships existing between depth of water retained per foot of soil, the weight percentage present, and the soil apparent specific gravity, in its present form it does not permit the actual numerical values for d to be very readily obtained. Numerous methods of graphing these relationships on a single plane for practical use readily suggest themselves, but probably the most useful representation is that given by a nomogram of the third class (1) consisting of three parallel straight lines. It is not difficult to construct or read and permits easy, direct interpolation between scale graduations during its use. Fig. 2 is a nomogram which has been prepared, like Fig. 1, from equation 3 by letting $D = 1$, whereupon

$$\log \frac{P_w}{100} + \log s_a - \log d = 0 \qquad 4$$

Calculations by means of the nomogram are made in the usual way. A straight edge, preferably a thin, transparent strip of celluloid upon the lower face of which is lightly engraved a straight line, is placed on the nomogram so that the straight line intersects known values on two of the graduated scale lines after which the third, desired value may be read at the point of intersection of line and third scale line.

Different uses of this nomogram are listed in Table 1. When using the nomogram, it must be recalled that if values of d are required corresponding to soil depths greater than $D = 1$, the d values read off the nomogram must be multiplied by the actual depth of soil.

EQUATIONS AND NOMOGRAM FOR RELATIONS BETWEEN SOIL DENSITIES AND TOTAL POROSITY

The total porosity, E, of the soil, defined as the ratio of the sum of the volumes of the nonsolid phases to the sum of the volumes of

[5]Since d = a depth, this fact is rather readily suggested by a vertical distance. When $D = 1$ foot, and a body of soil 1 square foot in cross section is considered, d represents the quantity of water, as a fraction of a cubic foot, present in 1 cubic foot of soil.

The plots of each type were arranged in a Latin square. The center 16 feet of the 18-foot plots was used for forage determinations. The plots were seeded in 1938 and harvested once in 1938 and three times in 1939. In 1938, all rows of each plot were used in the dry matter determinations, but in 1939 only the center row of the multiple-row plots was used.

The percentage of dry matter in the green and air-dry forage for 55 strains and varieties of the U. S. Department of Agriculture Uniform Alfalfa Nursery seeded in 1937 was determined for the third cutting in 1938 and the three cuttings in 1939. The center 16 feet was harvested from the 18-foot plots (single rows 3 feet apart). Duplicate plots (two replications) of each strain or variety were available in this experiment.

In all cases the data were analyzed by the variance method to determine the statistical significance of differences in the percentage dry matter in the green and in the air-dry forage of the various varieties and strains. The test of significance was made by computing F values (4); that is, variety variance/error variance.

The plots were weighed green as soon as cut, field-cured enough before putting into cloth sacks to prevent spoilage, uniformly air-dried in an open shed, and weighed air-dry several weeks after storage. After weighing, the air-dry samples were ground in a "Wiley mill" and a representative 10-gram sample of each dried in an oven. The computation for percentage dry matter in air-dry samples was $\frac{\text{oven-dry weight of sample}}{10} \times 100$. The percentage dry matter in the green forage was computed as follows: $\frac{\text{air-dry weight of plot}}{\text{green weight of plot}} \times$ per cent dry matter in the air-dry forage. All of the green weights and all of the air-dry weights for each experiment were taken within one day to minimize changes in moisture content caused by variations in weather conditions.

PERCENTAGE DRY MATTER IN GREEN FORAGE

The data for percentage dry matter in the green forage in Tables 1 and 2 show that some varieties differ significantly in this respect. For the experiment with five varieties (Table 1) the difference between the highest and lowest percentage expressed in per cent of the 25-plot average for each cutting was 3.52, 3.86, 3.81, and 6.44 for the one cutting in 1938 and the first, second, and third cuttings in 1939, respectively. A similar analysis of the data for the 55-strain experiment shows that the extreme differences in percentage of the 2-plot average were 19.21 to 34.24.

The different types of plots also show a difference in moisture content of the five varieties tested, indicating that yields based on green weights show significant differences between varieties for all types of plots except for the five-row plots with rows 12 inches apart. These data indicate that varieties of alfalfa cut on the same day may contain different amounts of moisture in the green forage and that serious inaccuracies can arise by estimating dry yields from the green weights of alfalfa plots.

The percentage dry matter in the green forage was found to vary between replications of the same experiment (Table 3). Significant differences were found in 12 of the 19 sets of data examined.

TABLE 1.—*Variations in the percentage of dry matter in the green and in the air-dry forage for five varieties of alfalfa grown in five types of plots harvested in 1938 and 1939.*

Type of plot	1938 cutting		1939 cuttings					
			1st		2nd		3rd	
	E†	D	E	D	E	D	E	D
Green Forage								
Single rows 3 feet apart	0.70	7.66*	1.93	4.36	0.18	6.41**	1.97	8.26
Single rows 20 in. apart	0.43	6.21*	0.60	3.49	0.26	4.99*	—	—
3 rows 20 in. apart	1.51	2.43	2.35	9.35	0.38	5.59	0.26	9.57**
3 rows 12 in. apart	2.07	3.92	0.30	7.11**	0.14	3.76*	0.31	7.92**
5 rows 12 in. apart	3.06	5.02	1.82	4.62	0.78	3.66	0.76	5.91
25 plots all types	1.55	3.52**	1.42	3.86	0.35	3.81**	0.39	6.44**
Air-Dry Forage								
Single rows 3 feet apart	0.43	0.38	0.050	0.05	0.034	0.26	0.078	0.36
Single rows 20 in. apart	0.10	0.65	0.028	0.15	0.066	0.24	—	—
3 rows 20 in. apart	0.346	0.32	0.098	0.24	0.132	0.43	0.120	0.21
3 rows 12 in. apart	0.189	0.26	0.050	2.21	0.073	0.17	0.150	0.21
5 rows 12 in. apart	0.105	0.66	0.045	0.53*	0.060	0.50	0.045	0.26
25 plots all types	0.23	0.17	0.055	0.12	0.076	0.11	0.098	0.21

†E = Error variance. $D = \frac{\text{range} \times 100}{\text{average}}$.
Single and double star if F exceeds 5% and 1% levels, respectively.

TABLE 2.—*Variations in the percentage of dry matter in the green and in the air-dry forage for 55 strains of alfalfa harvested in 1938 and 1939.*

	Green forage				Air-dry forage			
	1938, 3rd cutting	1939 cuttings			1938, cutting	1939 cuttings		
		1st	2nd	3rd		1st	2nd	3rd
Difference (highest-lowest strain)	4.50	6.90	5.25	5.00	1.55	0.55	1.55	0.75
(Difference/average) 100	19.21	34.24	22.24	19.97	1.68	0.59	1.68	0.82
F values (variety/error variance)	1.99*	0.98	2.03*	1.15	1.88*	1.71*	3.21†	0.74

*Greater than 5% point.
†Greater than 1% point.

PERCENTAGE DRY MATTER IN AIR-DRIED FORAGE

The varieties in the five-variety experiment (Table 1) contained so nearly the same amount of dry matter when air-dry that significant

differences were not detected, except in the first cutting for the five-row plots. In three of the four cuttings studied of the 55-strain experiment (Table 2) significant differences were found. However, the greatest errors were only 1.68, 0.59, 1.68, and 0.82% for the third cutting in 1938 and the first, second, and third cuttings in 1939, respectively.

TABLE 3.—*F values (block variance/error variance) to determine the significance of differences in percentage dry matter of the green forage between the replications of an experiment with five replications and five varieties for each of five types of plots.*

Types of plots	1938 cutting	1939 cuttings		
		1st	2nd	3rd
Single rows, 3 feet apart	1.46	3.69*	5.01*	0.42
Single rows, 20 in. apart	10.53†	1.18	13.25†	—
3-rows, 20-in. rows, 20-in. alleys	2.95	0.46	3.82*	2.89
3-rows, 12-in. rows, 20-in. alleys	14.68†	2.48	27.80†	6.74†
5-rows, 12-in. rows, 20-in. alleys	4.20*	8.29†	10.39†	5.03*

*Greater than 5% point.
†Greater than 1% point.

DISCUSSION

The acre yield of alfalfa in variety and strain experiments often is reported in pounds or tons of oven-dry forage, or of forage containing a definite amount of moisture such as 12%. The yield of oven-dry forage may be obtained by oven drying the forage of each plot as is possible with small plots with rows 1 rod long. With large plots it is obtained by reducing field weights of green or field-cured forage to oven dryness from data secured on samples drawn at the time of weighing. Proper procedures in ascertaining oven-dry yields result in very accurate data. However, in some instances the plots of experiments with several to many strains of alfalfa are weighed green and the oven-dry plot yields computed from the average percentage dry matter of a few random samples taken during the period of harvest and without regard to the sampling of each variety. This method results in serious errors as strains and replications may vary in percentage dry matter at any one date of cutting. While the green weight method of determining forage yields most often is used in experiments of many strains and few replications, the data presented show that the errors of the green weight method are much higher for such experiments than they are for those with few varieties and many replications. The field weights of green forage of each variety should be reduced to oven-dryness or some other standard with adequate data obtained from sampling each variety. The safe procedure is to sample each plot.

The data presented show that the varieties and strains of alfalfa examined had about the same percentage dry matter within cuttings after thoroughly drying in the air under cover. This indicates that air-dry yields of varieties are comparable within cuttings. However,

some error will occur when different cuttings are compared or when different years are compared. If comparisons between cuttings or between years are wanted, the forage yield should be computed to oven dryness or a definite dry matter content such as 88%. This can be done by oven drying an adequate air-dry sample from each cutting of the experiment without regard to variety.

SUMMARY

The percentage dry matter in a number of varieties of alfalfa was determined in the green forage and in the forage air dried under cover. The number of varieties or strains was 5 in one experiment and 55 in the other. There were 25 plots of each variety in the former and 2 in the latter. All varieties were grown in nursery plots. Data are reported on four cuttings; one in 1938 and three in 1939.

The data show that some varieties and replications differ in percentage dry matter at the time of cutting and that the percentage dry matter in samples air dried under cover for several weeks was nearly equal in all varieties. In the experiment of five varieties the average maximum differences in dry matter between two varieties for the three cuttings in 1939 decreased as the number of replications increased. The lowest difference was found when 25 replications were used. In the experiment of the 55 strains, average maximum differences in dry matter between 2 varieties were much greater than those found where only 5 varieties with a greater number of replications were used. The dry matter differences in the air-dry samples were in the same order but were much smaller and not significant.

CONCLUSIONS

The percentage dry matter in green alfalfa varies sufficiently between some varieties at the time of cutting to make forage yields based on green weights inaccurate. Green weights should be reduced by plots to oven dryness, to an exact percentage of dry matter, or to air dryness. Forage yields of alfalfa varieties based on samples or plots air dried under cover are nearly as accurate as those based on oven-dry weights. For comparisons between cuttings or between years, air-dry forage yields should be reduced to a definite percentage of dry matter.

LITERATURE CITED

1. ARNY, A. C. The dry matter content of field-cured and green forage. Jour. Amer. Soc. Agron., 8:358–363. 1916.
2. MCKEE, ROLAND. Moisture as a factor of error in determining forage yields. Jour. Amer. Soc. Agron., 6:113–117. 1913.
3. MCROSTIE, G. P., and HAMILTON, R. I. Accurate determination of dry matter in forage crops. Jour. Amer. Soc. Agron., 19:243–251. 1927.
4. SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934.
5. VINALL, H. N., and MCKEE, ROLAND. Moisture content and shrinkage of forage and the relation of these factors to the accuracy of experimental data. U.S.D.A. Bul. 353. 1916.

6. WEIHING, RALPH M., and ROBERTSON, D. W. Forage yields of five varieties of alfalfa grown in nursery rows and field plots. Jour. Amer. Soc. Agron., 33: 156–163. 1941.
7. WILKINS, F. S., and HYLAND, H. L. The significance and technique of dry matter determinations in yield tests of alfalfa and red clover. Iowa Agr. Exp. Sta. Res. Bul. 240. 1938.
8. ———, and WESTOVER, H. L. Turkestan alfalfa as compared with Grimm for wilt-infected soils in Iowa. Jour. Amer. Soc. Agron., 26:213–222. 1934.

NOMOGRAMS FOR RAPID CALCULATION OF SOIL DENSITY, WATER CONTENT, AND TOTAL POROSITY RELATIONSHIPS[1]

G. B. BODMAN[2]

CALCULATIONS having immediate practical utility in applied soil physics may be quickly made if attention is given to the development of the most direct expressions relating the soil properties concerned. Charts and tables may then be prepared to cover the most important ranges so that the desired results may be seen at a glance. Examples are to be found in the nomograms which have been prepared for aid in mechanical analysis calculations (3, 6)[3] for a variety of experimental conditions, in tables compiled for use in irrigation practice (4), and in nomograms indicating the probable relations between certain soil properties and the most suitable spacing of tile for soil drainage (5).

It is recognized that numerical values estimated from graphs are seldom so accurate as those obtained by direct calculation, or from carefully prepared tables. Graphs usually have the advantage, however, of presenting in a given space values covering wider ranges of relationships than tables. Moreover, the accuracy obtainable is frequently adequate, particularly when the nature of the problem and the available measurements themselves preclude a high degree of exactness. But neither diagrams nor tables are any more reliable than the equations from which they are derived. It is important, therefore, that any basic assumptions which may have been made in the calculations be clearly understood by the user.

The diagrams which are presented here are designed to facilitate certain calculations involving some of the most simple and elementary properties of the soil, particularly in relation to water content and well-established empirical observations concerning penetration. They are based upon alignment charts (2) which for several years have been found useful for instructional purposes and which have also been used in laboratory and field practice. The relationships discussed are in common use in western United States, but they may be frequently used to advantage wherever irrigation, drainage, watershed management, soil conservation practices, and other soil and water relations are under consideration.

EQUATIONS AND NOMOGRAM FOR SOIL AND WATER, VOLUME AND WEIGHT RELATIONS

The equation for the conversion of an amount of soil water from a mass to a volume ratio is given by

$$\frac{v_L}{v_S + v_L + v_G} = \frac{m \cdot s_A \cdot \rho_L}{\rho'_L} \qquad \text{I}$$

[1]Contribution from the Division of Soils, University of California, Berkeley, Calif. Received for publication June 1, 1942.

[2]Professor of Soil Physics.

[3]Figures in parenthesis refer to "Literature Cited", p. 892.

which, if $\rho'_L = \rho_L$, becomes

$$\frac{v_L}{v_A} = m \cdot s_A \qquad 2$$

in which

v_L = volume of liquid in soil (soil water)
v_S = volume of solid (inorganic and organic soil particles)
v_G = volume of gas (soil air)
v_A = $v_S + v_L + v_G$ = apparent volume of undisturbed soil
m = mass of water per unit mass of soil, after drying at 105°C
s_A = apparent specific gravity of undisturbed soil
ρ_L = absolute density of water in bulk
ρ'_L = absolute density of water in soil

The equation takes no account of soil water which is not removed at 105°C and assumes that all losses in weight at this temperature are due to the removal of soil water. In the final form 2 of the equation it is further assumed that no difference exists between the absolute density of water in bulk and that of water dispersed, by numerous forces, throughout the porous body of soil and removable at the conventional temperature. This assumption may not be permissible in certain calculations, particularly when dealing with that fraction of the soil water which is most closely associated with the solid phase. It is probable, however, that for field soil calculations the error introduced is of little consequence in comparison with those errors which persist owing to soil heterogeneity, even in what appears to be a field of uniform soil of a single soil type.

It will be observed that the ratios included in equation 1 are dimensionless. Provided that like dimensions are expressed in units of the same system of measurement, therefore, the ratios are independent of the units used. In practice the following substitutions are commonly made:

$$\text{(i)}\ \frac{v_L}{v_A} = \frac{d}{D},$$

$$\text{(ii)}\ m = \frac{P_w}{100}$$

in which, in addition to those symbols which have already been defined, d and D, given in the same units of length, are the corresponding depths of water and unaltered soil, respectively, per unit cross-sectional area of a vertical column of unaltered soil, and P_w equals the grams of water present per 100 grams of dry soil, or the percentage water content by weight.

The ratio d/D in (i) may be easily visualized by considering the result of extracting all water which is removable at 105°C from a vertical column of soil, *in situ*, and collecting the water in a vertical-walled vessel of the same internal cross section as the cross section of the soil column. The depth of water, d, in the vessel may then be compared with the depth of soil, D, from which it was obtained. It should be pointed out that for many calculations in irrigation and

drainage practice it is assumed that the removal of water from, and its addition to, the soil is without significant effect upon the apparent volume of the soil. Whereas this is probably substantially true for subsoils and at all depths in many sandy soils, it is certainly not true for all surface soils, highly organic soils, clays, or others which shrink and swell when dried or wetted. Evidently the greater the depth of soil under consideration and the less the volume change which it undergoes with changes in water content, the less is the error.

Since when measuring the mass of a given volume of soil *in situ* it is usually the apparent density, ρ_A, in grams per cc which is actually determined and reported, and in the C.G.S. system the absolute density of water may be regarded as unity, the apparent density may conveniently replace the apparent specific gravity in equation 1 with no loss in accuracy.[4] If the apparent density of the undisturbed soil has been measured in pounds per cubic foot it must, of course, be converted to apparent specific gravity (a dimensionless value) by dividing by the mass of 1 cubic foot of water, except when graphical provision has already been made for this transformation in nomograms and charts.

Equation 1 then assumes the form which is so widely used in irrigation practice,

$$\frac{d}{D} = \frac{P_w}{100} \cdot s_A \qquad 3$$

Evidently if three of the four possible variables in this equation are known, the fourth may be calculated. The number of variables may be most conveniently reduced to three by letting D equal unit depth of soil.

Equation 3 may be represented graphically by a solid, such as is drawn isometrically in Fig. 1. In this solid all possible magnitudes of d, when $D = 1$, are given by the slightly curved, sloping surface facing the observer, for $0 < P_w < 63\%$ and $1.00 < s_A < 1.75$. The magnitude of d per unit depth of soil is obtained from the height on the sloping surface of a point lying vertically above the point on the base which has the proper moisture content and apparent specific gravity coordinates. The broken lines on the surface indicate the positions of water depth, d, contours by intervals of one-tenth. The crest of the solid, where the vertical back (hidden from view) and sloping surface intersect, is defined by limitations imposed by the porosity of the soil upon its water-retentive capacity. Evidently, if the density of water remains unchanged upon entry into the soil, i.e., if the water is strictly incompressible, the maximum limiting volume (measured before being added to the soil) which can be retained cannot exceed the total pore volume. The actual volume of water retained after free drainage depends in general upon soil properties other than the gross porosity. In Fig. 1 the limiting porosities corresponding to different values of apparent density have been arbitrarily set by choosing a real density of 2.70 grams/cm^3, but the soil real density does not in any other

[4]For this reason the term apparent density is used in Fig. 2 (nomogram 1, right hand scales, B_1 and B_2).

respect affect the form of the solid figure, nor are the scale graduations affected.

Numerous experiments have shown that upon addition of water to a water-permeable soil and the maintenance at the soil surface, during the addition, of a constant energy level per gram of water, infiltration is at first very rapid and later proceeds more slowly. When surface addition of water has ceased, downward penetration of water into deeper layers of soil continues under isothermal conditions, but at a rate which diminishes over a long time period. The rate of penetration

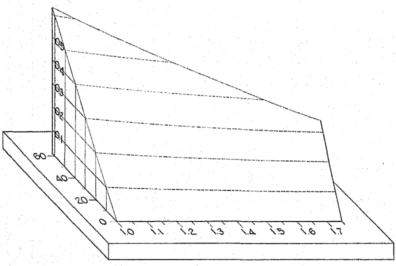


FIG. 1.—Isometric drawing of solid, representing interrelationships of soil properties designated by coordinates. Coordinates: Front, apparent specific gravity of soil, or apparent density in C. G. S. units; side, water content, percentage by weight, dry basis; vertical, depth, or volume, ratio of water to soil.

soon becomes so small that it may be neglected for many practical purposes, particularly by comparison with the rate of water loss due to transpiration. It has been repeatedly found that the average soil moisture content behind the advancing water front has, at the time of the practical cessation of downward movement, a magnitude characteristic of the soil at the time of the experiment. This moisture content is often called the field capacity. It must be measured in the soil during the exclusion of transpiration and evaporation losses when it may be concisely defined as that moisture content at which, on the moisture content-time graph $\Delta P_w/\Delta t$ begins to approach very closely to zero. Less time appears to be required for the soil to reach its field capacity when relatively dry soil is present beyond the wetting front than is the case when the soil is initially fairly moist to a considerable depth. The phenomenon is most strikingly demonstrated during the entrance of water into a texturally uniform, fairly dry

soil column. For soils of intermediate texture the field capacity has been shown by numerous investigators to be approximately equal to the moisture equivalent.

The conception of a field capacity has long been used in irrigation and related practice by the adaptation of equation 3 to the calculation of the requisite amount of water for increasing the water content of the soil from some initial water content, P_I, to the field capacity, P_{FC}, thus:

$$d = \frac{(P_{FC}\text{-}P_I) \cdot s_A \cdot D}{100}.$$

Equation 3 may be used for various purposes. Its common uses are described in Table 1.

Although the solid represented in Fig. 1 has certain special advantages[5] for indicating the relationships existing between depth of water retained per foot of soil, the weight percentage present, and the soil apparent specific gravity, in its present form it does not permit the actual numerical values for d to be very readily obtained. Numerous methods of graphing these relationships on a single plane for practical use readily suggest themselves, but probably the most useful representation is that given by a nomogram of the third class (1) consisting of three parallel straight lines. It is not difficult to construct or read and permits easy, direct interpolation between scale graduations during its use. Fig. 2 is a nomogram which has been prepared, like Fig. 1, from equation 3 by letting $D = 1$, whereupon

$$\log \frac{P_w}{100} + \log s_a - \log d = 0 \qquad 4$$

Calculations by means of the nomogram are made in the usual way. A straight edge, preferably a thin, transparent strip of celluloid upon the lower face of which is lightly engraved a straight line, is placed on the nomogram so that the straight line intersects known values on two of the graduated scale lines after which the third, desired value may be read at the point of intersection of line and third scale line.

Different uses of this nomogram are listed in Table 1. When using the nomogram, it must be recalled that if values of d are required corresponding to soil depths greater than $D = 1$, the d values read off the nomogram must be multiplied by the actual depth of soil.

EQUATIONS AND NOMOGRAM FOR RELATIONS BETWEEN SOIL DENSITIES AND TOTAL POROSITY

The total porosity, E, of the soil, defined as the ratio of the sum of the volumes of the nonsolid phases to the sum of the volumes of

[5]Since d = a depth, this fact is rather readily suggested by a vertical distance. When $D = 1$ foot, and a body of soil 1 square foot in cross section is considered, d represents the quantity of water, as a fraction of a cubic foot, present in 1 cubic foot of soil.

TABLE 1.—*Uses of nomograms.*

Information desired	Preliminary data required concerning soil	Relationship between soil properties	Result given on scale lettered	Significance* to be given to scale letters: A	B	C_1	C_2
Nomogram No. 1 (Fig. 2)							
1. Water content as volume percentage (P_v) in soil at a given weight percentage (P_w)	P_w; s_A	$\frac{P_v}{100}=\frac{P_w \cdot s_A}{100}$	C_2	P_w	s_A	—	$\frac{P_v}{100}$
2. Depth of water (d) present in 1 foot of soil at a given weight percentage water content (P_w)	P_w; s_A	$d=\frac{P_w \cdot s_A \cdot D}{100}$	C_1 or C_2	P_w	s_A	i	i
3. Depth of water ($d_{FC}-d_I$) which must be added to bring 1 foot of soil to its field capacity (P_{FC}) from a given initial water content (P_I)	P_{FC}; P_I; s_A	$d_{FC}-d_I=\frac{(P_{FC}-P_I) \cdot s_A \cdot D}{100}$	C_1 or C_2	$P_{FC}-P_I$	s_A	i	i
4. Depth of water ($d_{FC}-d_{WP}$) which 1 foot of soil at known permanent wilting percentage (P_{WP}) will retain against gravity and release for plant growth when at its field capacity (P_{FC})	P_{FC}; P_{WP}; s_A	$d_{FC}-d_{WP}=\frac{(P_{FC}-P_{WP}) \cdot s_A \cdot D}{100}$	C_1 or C_2	$P_{FC}-P_{WP}$	s_A	i	i
5. Depth of penetration (L) into soil of a given applied depth (d_S) of water for soil of a given initial water content (P_I) and field capacity (P_{FC}):							
(i) First find d′ corresponding to $P_{FC}-P_I$ for 1 foot in depth of soil	P_{FC}; P_I; s_A	$d'=d_{FC}-d_I=\frac{(P_{FC}-P_I) \cdot s_A \cdot D}{100}$	C_2	$P_{FC}-P_I$	s_A	i	i
(ii) Divide d_s by d′	d_S; d′	$L=\frac{d_S}{d'}$	—	—	—	—	—
6. Apparent density of soil in gm/cm³ when given in lbs/ft³ and *vice versa*	ρ_A in F. P. S. or C. G. S. units	—	B	—	i	—	—

Nomogram No. 2 (Fig. 3)							
7. Total porosity (E)	$\rho_R; \rho_A$	$E = \frac{\rho_R - \rho_A}{\rho_R}$	C_1	i	i	i	—
8. Void ratio (e)	$\rho_R; \rho_A$	$e = \frac{\rho_R - \rho_A}{\rho_A}$	C_2	i	i	—	i
9. Total porosity (E) when given void ratio (e) and *vice versa*	e or E	$\left\{ E = \frac{e}{1+e} \quad e = \frac{E}{1-E} \right.$	C_1 or C_2	—	—	i	i
Nomograms Nos. 1 and 2 (Figs. 2 and 3)							
10. Weight percentage water content when soil is fully saturated with water ($P_{W\text{-}S}$):							
(i) Use nomogram 2 to obtain E	$\rho_R; \rho_A$	$E = \frac{\rho_R - \rho_A}{\rho_R}$	C_1	i	i	i	—
(ii) Use nomogram 1 to obtain $P_{W\text{-}S}$	E; s_A	$P_{W\text{-}S} = \frac{100 \cdot E}{s_A}$	A	i	s_A	–	E
11. That fraction (E_v) of the total apparent volume of a soil which loses water during free drainage:							
(i) Use nomogram 1 to obtain d_{FC}	$P_{FC}; s_A$	$d_{FC} = \frac{P_{FC} \cdot s_A \cdot D}{100}$	C_2	d_{FC}	s_A	i	i
(ii) Use nomogram 2 to obtain E	$\rho_R; \rho_A$	$E = \frac{\rho_R - \rho_A}{\rho_R}$	C_1	i	i	i	—
(iii) Subtract		$E_v = E - \frac{d_{FC}}{D}$	—	—	—	—	—

*i indicates that the scales are to be given the significance indicated on nomogram.

solid, liquid, and gaseous phases, is given by

$$E = \frac{V_A - V_S}{V_A} \qquad 5$$

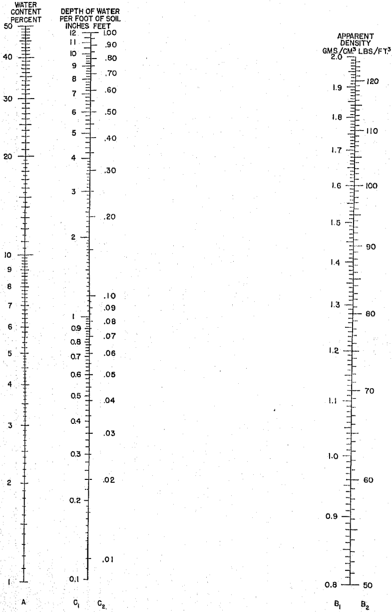


FIG. 2.—Nomogram No. 1 for estimating soil and water relationships.

For unit mass of water-free soil (at 105°C) and neglecting the mass of the gaseous phase, this becomes

$$E = \frac{1/\rho_A - 1/\rho_R}{1/\rho_A}$$

$$= \frac{\rho_R - \rho_A}{\rho_R}$$

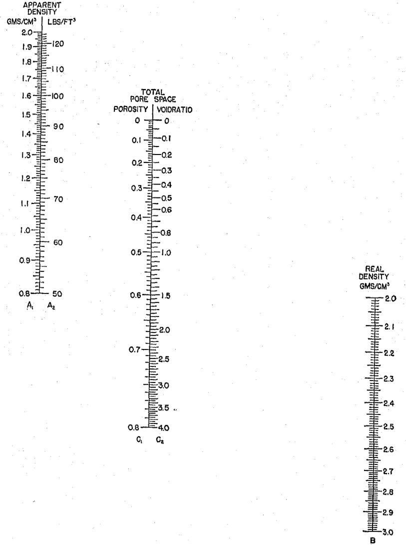


FIG. 3.—Nomogram No. 2 for estimating soil density and total porosity relationships.

in which ρ_R = absolute density of the solid phase,[6] and ρ_A = apparent density of the soil. Both real and apparent densities must be given in the same units of measurement. This equation indicates the commonly used method for calculating the total porosity of the soil. Hence,

$$\frac{\rho_A}{\rho_R} = 1 - E \qquad 6$$

and

$$\log \rho_A - \log \rho_R - \log (1 - E) = 0 \qquad 7$$

Fig. 3 is a nomogram relating the real and apparent densities of the soil to its total porosity by means of equation 7.

In the field of soil mechanics the abundance of voids of all sizes is given by a very useful expression known as the void ratio, e, which is defined as

$$e = \frac{V_A - V_S}{V_S}$$

$$= \frac{\rho_R - \rho_A}{\rho_A}.$$

Thus,

$$\frac{\rho_R}{\rho_A} = 1 + e \qquad 8$$

and, substituting from equation 6

$$e = \frac{E}{1 - E} \qquad 9$$

This relationship between the porosity and the void ratio is shown by the scales C_1 and C_2 of Fig. 3. Table 1 indicates different uses of this nomogram.

SUMMARY

Some well-known equations from elementary soil physics are reviewed in the light of the major assumptions which they contain. From them certain widely used relationships dealing with volumes of water retention by soils, water penetration, irrigation practice, and drainage are developed in forms suitable for the preparation of graphs and alignment charts which express the relations concerned.

Two nomograms and a table are included which deal with these relationships and permit rapid estimation of the desired calculated values.

LITERATURE CITED

1. ALLCOCK, H. J., and JONES, J. REGINALD. The Nomogram: The Theory and Practical Construction of Computation Charts. London: Pitman and Sons, Ltd. 1932.

[6]It is here assumed that the absolute density of the soil can be accurately measured. It is known that this is not always the case, particularly for soils of high specific surface measured in polar liquids. The error introduced on this account is probably of no greater significance than that caused by assuming equality between ρ'_L and ρ_L in equation 1.

2. BODMAN, G. B. Laboratory experiments on the physical properties of soils. Univ. California Syllabus Ser., Syllabus IP, Univ. Calif. Press (mimeo). 1937.
3. CROWTHER, E. M. Nomographs for use in mechanical analysis calculations. Proc. First Int. Congress Soil Sci., Pt. II (Commission I): 399–405. 1928.
4. ISRAELSEN, ORSON W. Irrigation Principles and Practices. New York: Wiley and Sons. 1932.
5. NEAL, J. H. Proper spacing and depth of tile drains determined by the physical properties of the soil. Minn. Agr. Exp. Sta. Tech. Bul. 101. 1934.
6. WILLIS, E. A., ROBESON, F. A., and JOHNSTON, C. M. Graphical solution of the data furnished by the hydrometer method of analysis. Public Roads, 12: 208–215. 1931.

EFFECT OF DOLOMITIC LIMESTONE ON SOILS AND CROPS WHEN USED AS A NEUTRALIZING AGENT IN COMPLETE FERTILIZERS[1]

E. R. COLLINS AND J. J. SKINNER[2]

NEUTRALIZING the acidity of fertilizers caused by acid-forming nitrogen salts with dolomitic limestone has generally given increased yields of crops on many soil series in the South (1, 6, 8, 10, 11, 12).[3] Dolomitic limestone in addition to neutralizing the acid-forming tendencies of fertilizer supplies calcium and magnesium. The relative importance of these two functions of dolomitic limestone may vary with crop and soil. The decomposability of dolomitic limestone in the soil and the availability of its magnesium to crops when used to make non-acid-forming fertilizers have been shown to be of considerable importance in crop fertilization (4, 5).

Greenhouse studies with cotton on the decomposition of limestone of different degrees of fineness on different soil types have shown that calcined dolomitic limestone, 80-mesh and finer, supplies a large part of the magnesium needs of plants; and that the pH and buffer capacity of the soil are the major soil factors involved in dolomitic limestone decomposition (4, 5). Results of field experiments with cotton, sweet potatoes, and Irish potatoes on Coastal Plain soils of North Carolina reported in this paper contribute additional soil and plant data on the subject.

PLAN OF THE EXPERIMENT

Fertilizers were formulated with 67% of the nitrogen from ammonium sulfate and 33% from uramon, superphosphate, and muriate of potash. This acid-forming fertilizer was compared with one made non-acid-forming with dolomitic limestone approximately 75% of which would pass through a 60-mesh screen. The treatments were in randomized blocks with five replications. Each plot was four rows, 50 feet long. The data were taken from two inside rows. Fertilizers were applied and mixed with the soil in the seed furrow 10 days before planting. On each plot the respective fertilizer treatment and crop were repeated each season for the duration of the experiment which was 4 years in the case of cotton and sweet potatoes and 3 years in the case of Irish potatoes. The details of treatments, soils, and fertilizer rates are shown in Table 1.

RESULTS WITH COTTON

The results in Table 2 show highly significant differences each year in yield of seed cotton from fertilizers formulated neutral with dolomitic limestone over acid-forming fertilizers. The increases were 175, 349, 466, and 184 pounds of seed cotton, respectively, for the 4 years.

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C., and the Division of Cotton and Other Fiber Crops and Diseases, Bureau Plant Industry, U. S. Dept. of Agriculture. Received for publication June 1, 1942.

[2]Associate Agronomist, North Carolina Agricultural Experiment Station, and Senior Biochemist, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 901.

TABLE 1.—*Details of treatments, soils, and fertilizer rates.*

Crops	Rate, lbs.	Fertilizers: Analysis $N\text{-}P_2O_5\text{-}K_2O$	Fertilizers: Equivalent acidity, limestone per ton, lbs.	Soil type	Duration of experiment, years
Cotton........	600	6–8–6	500	Norfolk sandy loam	4
Sweet potatoes.	1,100	3–8–6	250	Norfolk loamy fine sand light phase	4
Sweet potatoes.	1,100	3–8–6	250	Norfolk loamy fine sand heavy phase	4
Irish potatoes..	2,000	7–6–8	585	Portsmouth sandy loam	3
Irish potatoes..	2,000	7–6–8	585	Bladen fine sandy loam	3

The results in Fig. 1,[4] over a 3-year period, show a significant trend for higher magnesium in cotton plants grown with neutral fertilizers over those grown with acid-forming fertilizers. The calcium and potash values are not consistent and the averages for the 3-year period do not show appreciable difference between the two fertilizers.

The dry weights per plant given in Table 3 show that neutralizing the fertilizer resulted in a greater plant growth early in the season and that the larger growth was maintained throughout the season. The decrease for the September 3, 1940, period was due to shedding of leaves.

The potassium, magnesium, and calcium in grams per plant logically show a higher content of each in the larger plants produced by the neutral fertilizers. The larger dry weight per plant and the yield of cotton indicate more favorable growth conditions in the plots receiving the neutral fertilizer.

TABLE 2.—*Yield of cotton from acid-forming fertilizer and from the same fertilizer neutralized with dolomitic limestone applied to Norfolk sandy loam, Goldsboro, N. C.*

Fertilizer application equivalent to 600 lbs. per acre annually of 6–8–6	Pounds seed cotton per acre				
	1937	1938	1939	1940	Average
Acid-forming fertilizer.........	877	1,037	513	1,168	899
Fertilizer neutralized with dolomitic limestone...........	1,052*	1,386*	979*	1,352*	1,192*

*Highly significant increase over acid-forming fertilizers.

[4]Methods of the Association of Official Agricultural Chemists were used. For analyses, four plants were taken from each treatment in the five replications and the 20 plants were composited for each determination. Each figure represents the average of four analyses on different samples of 20 plants obtained as four plants from each of the five replications.

TABLE 3.—*Effect of neutralizing acid-forming fertilizer with dolomitic limestone on growth of cotton as indicated by dry weights on Norfolk sandy loam.*

Sampling date, 1939	Av. dry weight per plant, grams		Sampling date, 1940	Av. dry weight per plant, grams	
	Acid-forming fertilizer	Fertilizer neutralized with dolomitic limestone		Acid-forming fertilizer	Fertilizer neutralized with dolomitic limestone
June 1	9.0	12.1	June 1	6.2	8.5
July 25	23.7	43.2	July 2	55.4	76.7
Aug. 14	150.4	180.4	Aug. 6	137.5	149.3
Sept. 9	95.1	111.2	Sept. 3	340.6	296.3

The plant composition data indicate that dolomitic limestone used to make non-acid-forming fertilizers provides available magnesium for cotton plants and that the absorption of potash and calcium by the crop is not materially changed by this type of fertilizer.

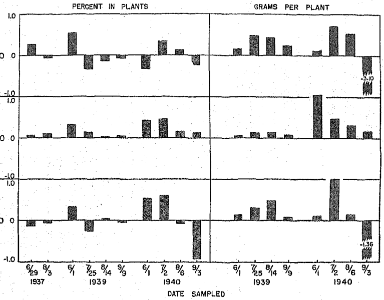


FIG. 1.—Increased or decreased intake of potash, magnesium, and calcium by cotton due to neutralizing acid fertilizer with dolomitic limestone.

In 1937, the pH of the experimental area was 5.6 to 5.7. The data in Table 4 show that in 1940 the pH of the plots receiving non-acid-forming fertilizer was 5.6, and of the plots receiving acid-forming fertilizer, 4.9. The favorable effect of the non-acid-forming fertilizer may be due in part to the level of pH maintained in the soil. Peech (7) found that liming not only assures adequate supplies of calcium and magnesium but also reduces leaching of cations applied as neutral salts. The latter tends to conserve the fertilizer constituents.

TABLE 4.—*Influence of dolomitic limestone in fertilizer on the pH and available K_2O, MgO, and CaO of the soil in the cotton root zone on Norfolk sandy loam, Goldsboro, N. C., soil sampled, October, 1940.*

Fertilizer treatment equivalent to 600 pounds per acre 6-8-6 in 1937–38–39–40	pH	Pounds per acre in the soil		
		K_2O	MgO	CaO
Acid-forming fertilizer	4.9	113	53	250
Fertilizer neutralized with dolomitic limestone	5.6*	111	131†	315

*Significant increase.
†Highly significant increase.

The available potassium, magnesium, and calcium of the soil were determined by methods of Carolus (3) and Miles (9) on samples taken at the end of the crop year in 1940. The soil for analysis was taken from the middle of the row and where the plant roots developed. The results are given in Table 4. The higher amounts of magnesium in the plots which received the neutral fertilizers at the end of the crop season and the higher magnesium content of these plants indicate that the magnesium in the dolomitic limestone is available. The calcium was increased, but the potash content of the soil did not vary due to neutralizing the fertilizer. This indicates that there was no appreciable liberation of soil potash or increased fixation of added potash due to the dolomitic limestone.

The experiments with sweet potatoes and Irish potatoes were made on light sandy soils having a low pH value. The influence of acid-forming and non-acid-forming fertilizers on soil acidity is given in Table 5. The pH determinations were made by the glass electrode method. The sweet potato fertilizers containing 3% nitrogen have a low equivalent acidity and therefore would not markedly affect soil acidity, which is shown to be the case in experiments 1 and 2. The neutralized fertilizers show a trend to maintain a higher soil pH than the acid-forming fertilizers.

At the end of the third crop season the soil from the furrow of the Irish potato experiments had significantly lower pH for acid-forming fertilizer than for neutralized fertilizers. The annual use of 2,000 pounds per acre of a non-acid-forming 7–6–8 fertilizer containing 585 pounds of limestone per ton over the 3-year period did not raise the pH of these acid soils which have a relatively high buffer capacity. At no time during the 3 years was there any indication that the fertilizers formulated to be non-acid-forming increased the incidence of scab on these soils having a low pH value. The non-acid-forming fertilizers were used on the same plots each season throughout the period of the experiment.

The relative effect of these two types of fertilizers on yield are given in Table 6. The yields of sweet potatoes each year were significantly higher from neutral fertilizers than from acid fertilizers in experiments 1 and 2, except in 1937. Likewise, Irish potato yields in experiments 3 and 4 on the Portsmouth and Bladen soils were significantly greater from the neutral fertilizer, except on the Bladen

TABLE 5.—*Effect of acid-forming fertilizer and the same fertilizer neutralized with dolomitic limestone on the reaction of two soils planted to sweet potatoes and two soils planted to Irish potatoes in North Carolina.*

Soil type and location	Annual fertilizer per acre, lbs.	Acidity equivalent of fertilizer, limestone per ton, lbs.	Duration of experiment, years	pH of soil at end of experiment from†	
				Acid-forming fertilizer	Same fertilizer neutralized with dolomitic limestone
			Sweet Potatoes		
Exp. 1, Grandy Norfolk l. f. s.; light phase...	1,100	250	4	4.9	5.1
Exp. 2, Coinjock Norfolk l. f. s.; heavy phase..	1,100	250	4	4.9	5.1
			Irish Potatoes		
Exp. 3, Beaufort Portsmouth s. l.	2,000	585	3	4.5*	4.8
Exp. 4, Aurora Bladen f. s. l.	2,000	585	3	4.3*	4.7

†pH of soil when experiments were started: Exp. No. 1, 5.1; Exp. No. 2, 4.9; Exp. No. 3, 4.8; Exp. No. 4, 5.0.
*Significantly lower than neutralized fertilizer plots.

soil in 1939. The soil of the five blocks of these experiments was unusually uniform in texture and fertility. There was only a slight variation in yield in the replicated plots. All four experiments gave highly

TABLE 6.—*Yield in bushels per acre of sweet potatoes and Irish potatoes grown with acid-forming and non-acid-forming fertilizers.*

Year	Sweet potatoes				Irish potatoes			
	Norfolk f. s. l.				Portsmouth s. l.		Bladen f. s. l.	
	Light phase, Grandy, N. C., No. 1		Heavy phase, Coinjock, N. C., No. 2		Beaufort, N. C. No. 3		Aurora, N. C., No. 4	
	Acid fertilizer	Neutral fertilizer	Acid fertilizer	Neutral fertilizer	Acid fertilizer	Neutral fertilizer	Acid fertilizer	Neutral fertilizer
1937	164	173	160	157	—	—	—	—
1938	179	203†	162	173†	186	193*	218	274†
1939	152	188†	160	183†	247	260†	233	226
1940	116	131†	118	138†	161	183†	262	266*
Average	160	174†	150	163†	198	212†	238	255†

*Significant increase over acid fertilizers.
†Highly significant increase over acid fertilizers.

significant increases for the neutral fertilizers when the average of all years is considered.

Since there was only a slight change in the pH of the sweet potato soils due to the acidity of the fertilizers, calcium and magnesium as nutrients are probably the major factors responsible for larger yields.

Analysis of Irish potato plants grown in 1940 in experiments 3 and 4 were made and the results are given in Table 7. The greater absorption of magnesium and calcium where the fertilizers were made non-acid-forming with dolomitic limestone indicates the availability of these elements in the limestone. Carolus and Brown (2) also found that potatoes on moderately acid soils in Virginia obtained an adequate supply of magnesium from dolomitic limestone included in neutral fertilizers. The effect of neutral fertilizer on absorption of potassium is not consistent. On Portsmouth sandy loam, experiment 3, there was a greater absorption of potassium by plants fertilized with acid fertilizer, while the reverse occurred on the Bladen soil, experiment 4.

TABLE 7.—*Effect of dolomitic limestone in fertilizer on absorption of potassium, magnesium, calcium, and phosphorus by Irish potatoes on two soil types in North Carolina.*

Fertilizer application, equivalent of 2,000 lbs. per acre, 7-6-8, annually 1938-40	Percentage in plants sampled June 7, 1940			
	K_2O	MgO	CaO	P_2O_5
Exp. 3, Portsmouth s. l., Beaufort:				
Acid-forming fertilizer	2.27	0.86	2.58	0.73
Fertilizer neutralized with dolomite limestone	1.83	1.59	2.98	0.62
Exp. 4, Bladen f. s. l., Aurora:				
Acid-forming fertilizer	1.87	0.76	2.92	0.70
Fertilizer neutralized with dolomite limestone	2.22	1.25	3.43	0.68

Further data on the availability of magnesium in dolomitic limestone applied in fertilizers are given in Table 8. Tests were made for available calcium, magnesium, potassium, and phosphorus in the soil of the root zone by the sodium acetate (3) and sodium perchlorate (9) extraction methods to ascertain the effect of the limestone on the availability of potassium and phosphorus in the soil and the availability of the calcium and magnesium added in the limestone. There was a significant increase in magnesium in both soils where the neutral fertilizer was used. The relative amount of potassium, calcium, and phosphoric acid in the plots receiving different types of fertilizers is not consistent and the differences are not significant.

These data also indicate that the magnesium of dolomitic limestone added to fertilizers to make them non-acid-forming is rather rapidly available to the crop and that the limestone does not materially influence the availability of potassium in the soils to crops.

SUMMARY

Fertilizers formulated to be non-acid-forming with dolomitic limestone gave significantly higher yields of cotton, sweet potatoes, and

TABLE 8.—*Influence of dolomitic limestone in fertilizers on supply of available bases and phosphorus of four soil types planted to sweet potatoes and Irish potatoes in North Carolina.*

Crop, soil, location, and fertilizer	Available nutrients in soil from surface of row after plowing out potatoes in 1940, lbs. per acre							
	Sodium acetate method				Sodium perchlorate method			
	K_2O	MgO	CaO	P_2O_5	K_2O	MgO	CaO	P_2O_5
Sweet Potatoes								
Exp. 1, Norfolk l. f. s., light phase, Grandy								
Acid fertilizer	70	23	467	5	113	24	533	3
Fertilizer neutralized with dolomite limestone	60	51*	667	1	140	45*	400	3
Exp. 2, Norfolk l. f. s., heavy phase, Coinjock								
Acid-forming fertilizer	65	45	607	9	129	47	687	9
Fertilizer neutralized with dolomite limestone	76	85*	580	11	130	74*	693	9
Irish Potatoes								
Exp. 3, Portsmouth s. l., Beaufort								
Acid-forming fertilizer	372	73	1,542	22	414	239	3,000	22
Fertilizer neutralized with dolomite limestone	209	128*	1,400	23	338	300*	2,900	28
Exp. 4, Bladen f. s. l., Aurora								
Acid-forming fertilizer	96	79	1,217	19	259	193	2,483	13
Fertilizer neutralized with dolomite limestone	93	123*	1,389	17	256	243*	2,544	10

*Highly significant increase over acid-forming fertilizers.

Irish potatoes than did acid-forming fertilizers on Coastal Plain soils in North Carolina.

Neutralizing the fertilizer with dolomitic limestone maintained soil pH at approximately the original level; increased total magnesium in the plant and the available magnesium in the soil of the root zone; and increased total calcium in the plant with no appreciable change in the ultimate available calcium content of the soil or the potash content of the plant, indicating no appreciable liberation or fixation of the soil and fertilizer potash.

Acid-forming fertilizers decreased the pH of the soils in the cotton and Irish potato experiments where 600 pounds per acre of a fertilizer having an equivalent acidity of 500 pounds per ton of limestone were used annually on cotton for 4 years, and 2,000 pounds per acre of a fertilizer having an equivalent acidity of 585 pounds of limestone per ton were used annually on potatoes for 3 years. The soil's pH was not decreased where 1,100 pounds per acre of a fertilizer having an equivalent acidity of 250 pounds of limestone per ton were used annually on sweet potatoes for 4 years.

LITERATURE CITED

1. ANTHONY, J. L., PITNER, JOHN, and DORMAN, CLARENCE. Neutral versus acid fertilizers. Miss. Agr. Exp. Sta. Bul. 338. 1940.
2. CAROLUS, R. L., and BROWN, B. E. Magnesium deficiency. I. The value of magnesium compounds in vegetable production in Virginia. Va. Truck Exp. Sta. Bul. 89. 1935.
3. ————. The use of rapid chemical plant nutrient tests in fertilizer deficiency diagnosis and vegetable crop research. Va. Truck Exp. Sta. Bul. 98. 1938.
4. COLLINS, E. R., and SPEAR, F. R. Decomposition of dolomitic limestone in soils when used as a neutralizing agent in complete fertilizers. Jour. Assoc. Off. Agr. Chem., 22:142–147. 1939.
5. ————, ————. Decomposition of dolomitic limestone in fertilizers. Jour. Assoc. Off. Agr. Chem., 23:374–388. 1940.
6. COOPER, H. P. Fertilizer and liming practices recommended for South Carolina. S. C. Agr. Exp. Sta. Circ. 60. 1939.
7. PEECH, MICHAEL. Availability of ions in light sandy soils as affected by soil reactions. Soil Science, 51:473–485. 1941.
8. MATTHEWS, E. D. Results from the use of limestone and magnesium in cotton fertilizers in Georgia. Proc. Assoc. Southern Agr. Workers. 1938.
9. MILES, I. E. Rapid testing of soils for plant food deficiencies under Southern conditions. Soil Sci. Soc. Amer. Proc., 2:143–150. 1937.
10. SKINNER, J. J., MANN, H. B., COLLINS, E. R., BATTEN, E. T., and BLEDSOE, R. P. Adapting high analysis and concentrated fertilizers to cotton soils. Soil Sci., 44:1–22. 1937.
11. ————, and BATTEN, E. T. Effect of neutralizing fertilizers with dolomitic limestone and the response to potash fertilization of cotton on Onslow fine sandy loam. Commercial Fert. Yearbook, 1942: 56–60. 1942.
12. TIDMORE, J. W., and SIMMONS, C. F. The use of limestone in mixed fertilizers. Ala. Agr. Exp. Sta. Circ. 67. 1934.

BORON FERTILIZATION OF ALFALFA AND OTHER LEGUMES IN OREGON[1]

H. E. DREGNE AND W. L. POWERS[2]

IN a previous report, Powers (9)[3] discussed the historical development of the use of boron. In the Oregon studies, application of a solution containing 1 p.p.m. of boric acid corrected yellowing of alfalfa which occurred with four out of five soils included in a greenhouse trial in 1936. Field applications where similar yellowing occurred in the spring of 1937 resulted in striking improvement in growth and yields and established the economic value of boron for alfalfa and some other crops, particularly on the leached soils of northwestern Oregon. Yellow-top of alfalfa has been found on leached soils in a dozen or more states and the trouble has been corrected by boron applications.

Since the concentration range of boron between the minute amount necessary and that toxic is small, attention has been given recently to analytical determination of the amounts in available form in Oregon soils and the normal and critical concentrations in plants showing response. While several legumes have shown response to boron, only the alfalfa data will be summarized herein.

If carefully observed, the appearance of alfalfa yellow-top in dry weather may help to reveal the extent of boron-deficient areas. Alfalfa, when in need of boron, makes a staggy growth, the upper leaves turn reddish or bronze and then yellowish and shatter readily. The terminal bud becomes blighted and blooming and branching are restricted. Old stands of alfalfa may be most affected.

Application of an aqueous solution of ½ p.p.m. of boric acid as a spray on young sprouts of alfalfa may result in improvement in color and growth within a week. Branching, blooming, and seed formation may be aided later (Figs. 2 and 3).

Analysis of Oregon soil types by the method of Berger and Truog (1) is helping to locate boron-deficient areas, while analysis of alfalfa tissue is making possible the formulation of standards of critical and optimum boron levels with which new determinations can be compared.

EXPERIMENTAL

GREENHOUSE TRIALS

Boric acid used at rates of 20, 40, and 60 pounds an acre on duplicate pot tests in the greenhouse on Salkum gravelly clay loam in 1938 increased alfalfa hay yields in five cuttings 110, 92, and 129%, respectively (Fig. 1).

These same treatments applied to Amity silt loam with red clover

[1]Published as Technical Paper No. 413 with the approval of the Director of the Oregon Agricultural Experiment Station, Oregon State College, Corvallis, Ore., as a contribution of the Soils Department. Received for publication June 1, 1942.

[2]Research Fellow in Soils and Soil Scientist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 911.

gave average gains of 95, 82, and 61%, respectively, in two cuttings.

Boric acid used at 10-, 20-, and 30-pound rates on Springdale fine sandy loam from Union County increased alfalfa yields 37, 29, and 10%, respectively. With Austrian winter field peas, the gains were 14, 19, and 17%, respectively.

Boric acid used on Newberg sandy loam at the rates of 20, 40, and 60 pounds per acre increased alsike clover yields in duplicate jars by 29, 21, and −1%, respectively.

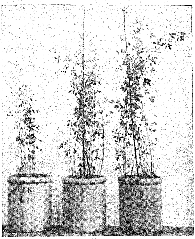


FIG. 1.—Alfalfa on Salkum gravelly clay loam, 1938. Left to right, check, NPK, and boron.

FIELD TRIALS

In the early work, boron was applied as boric acid in dilute solution. Later, the granular borax was broadcast like clover seed. Boron applied either as borax or boric acid has given very profitable increases in alfalfa yield (Table 1) on major soil types of northwestern Oregon, such as those of the Willamette series. The first cutting shows little yellow-top in normal years. The deficiency symptoms or increase in yield from boron additions come largely in the dry weather cuttings. On the College farm and near Reedville, the increase in yield has been 1.55 tons an acre annually for a 4-year period. This increase was secured from a single application of boric acid. On Amity silty clay loam near Suver, the maximum application, which also gave the greatest yield increase

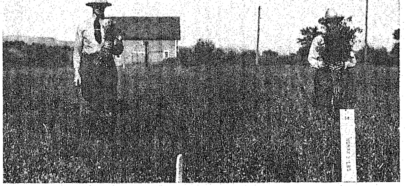


FIG. 2.—Alfalfa on Amity silty clay loam. Untreated at left vs. 3 pounds of borax at right.

TABLE 1.—*Response of alfalfa and other legumes to boron.*

Soil type	Farm and location	Kind of crop	Treatment*	Rate of borax per acre, lbs.	Cost of borax	Duration of test, years	Annual yields per acre, tons		Gain or loss, tons	Net profit from boron
							With boron	Without boron		
Willamette loam	H. Belton, New Era	Alfalfa, 1939–40, 2 cuttings yearly	Check	—	—	—	—	4.04†	—	—
			Superphos.	30	$0.75	2	4.79	3.56	1.23	$13.55
			Gypsum	30	0.75	2	5.21	3.40	1.81	20.57
			Lime	30	0.75	2	4.49	3.30	1.19	12.33
			KCl	30	0.75	2	4.23	3.37	0.86	7.10
			$NaNO_3$, superphos.	30	0.75	2	4.22	4.27	−0.05	−0.40
			$NaNO_3$, KCl	30	0.75	2	4.13	3.92	0.21	0.95
			N-P-K	30	0.75	2	3.94	3.79	0.15	3.42
			N-P-K	30	0.75	2	3.16	3.66	−0.50	−6.43
			N-P-K	30	0.75	2	3.52	3.44	0.08	0.11
Willamette silt loam	Hagg Bros., Reedville	Alfalfa, 1939–41, 2 cuttings a year	Check			4	—	3.82	—	—
			Boric acid	30	1.20	4	5.08	3.44	1.64	18.40
			$CaNO_3$, tr. phos.	40	1.00	3	4.46	3.52	0.94	9.10
			$CaNO_3$, KCl	40	1.00	3	3.99	3.42	0.57	21.10
			Checks	40	1.00	3	4.27	3.27	1.00	7.84
			Tr. phos., KCl	40	1.00	3	4.24	4.19	0.05	0.36
			$CaNO_3$, KCl, tr. phos.	40	1.00	3	4.56	3.61	0.95	9.60
			Gypsum	40	1.00	3	4.53	3.36	1.17	11.70
			Superphos.	40	1.00	3	5.18	3.41	1.77	19.70
Willamette silty clay	College irrigation field	Alfalfa, 1938–41, 3 cuttings yearly	Borax	10	0.25	4	4.24	3.95	0.29	3.23
			Borax	20	0.50	4	4.51	3.95	0.56	6.22
			Borax	30	0.75	4	5.20	3.95	1.25	14.25
			Boric acid	10	0.40	4	2.64	1.60	1.04	12.08
			Boric acid	20	0.80	4	3.15	1.60	1.55	17.85
Willamette silty clay loam	C. E. Berger, Albany	Alfalfa, 1 cutting 1940	Gypsum and borax	25	0.63	1	4.32	3.27	1.05	11.97

Amity silty clay	M. Davis, Suver	Alfalfa, 1939–41, 2 cuttings yearly	Borax, boric acid	40	2.60	3	3.47	3.17	0.30	1.00
			Superphos. and borax	30	0.75	3	3.38	3.17	0.21	1.77
			Borax	15	0.38	3	3.48	3.38	0.10	0.82
			Borax	45	1.13	3	4.17	3.48	0.69	7.15
			Boric acid	10	0.40	3	3.72	3.48	0.24	2.48
			Boric acid	20	0.80	3	3.58	3.20	0.38	3.76
			Boric acid	30	1.20	3	3.93	3.20	0.73	7.56
			Borax	30	0.75	3	3.92	3.07	0.85	9.45
			Borax	60	1.50	1	3.04	2.89	0.15	0.30
			Boric acid	60	2.40	1	4.19	2.92	1.27	12.84
Chehalis silty clay loam	M. Yocum, Ballston	Av. 7 tests, 1940, 1 cutting	Borax	20	0.50	1	2.07	2.10	−0.03	−0.86
Deschutes sandy loam	E. M. Wright, Tumalo	Alfalfa, 1940, 2 cuttings	Sulfur and borax	30	0.75	1	5.80	5.70	0.10	0.05
	Dennis & Austin, Vale	Alfalfa, 1 cutting	Tr. phos. and borax	30	0.75	1	2.16	1.65	0.51	3.33
Clay loam	E. E. Hawkins, Malheur County	Alfalfa, 1939–40, 3 cuttings	5–15–10, borax	20	0.50	2	9.71	9.52	0.19	1.02
———	Geo. Lawson, Yamhill County	Alfalfa, 1940, 2 cuttings	Borax	20	0.50	1	3.44	2.44	1.00	11.50
Loam	J. Houck, Malheur County	Alfalfa, 1940, 3 cuttings	Tr. phos., borax	30	0.75	1	4.48	3.99	0.49	3.17
———	Lee Johnson, Big Bend	Alfalfa, 1940, 3 cuttings	Tr. phos., borax	30	0.75	1	5.78	4.58	1.20	8.85
Willamette silty clay loam	R. Forester, Tangent	Ladino clover, 1940	Check, lime, borax	40	1.00	1	1.11	1.08	0.03	−0.64
Amity silty clay loam	College, Veterinary sheep pasture	Ladino hay, pastured, 1941	Borax	20	0.50	1	3.26	3.01	0.25	2.50
			Borax	40	1.00	1	2.71	3.01	−0.30	−4.60
			Borax	60	1.50	1	2.68	3.01	−0.33	−5.4[illegible]
			Borax	80	2.00	1	2.72	3.01	−0.29	−5.4[illegible]
Very fine sandy loam	V. Butler	Red clover hay, 1940	Tr. phos., borax	30	0.75	1	1.49	1.55	−0.06	−1.2[illegible]
Sisters gravelly sandy loam	Geo. Cyrus, Sisters	Alsike clover seed, 1940	Borax	30	0.75	1	8.25 (bu.)	5.33 (bu.)	2.92 (bu.)	27.2[illegible]
Olympic clay loam	C. T. Gilbert, Shaw	Oats and vetch hay, 1941	Check and borax	30	0.75	1	3.12	2.77	0.35	3.45
			Tr. phos., borax	30	0.75	1	3.54	3.42	0.12	0.69
			Checks and borax	20	0.50	1	2.32	2.56	−0.24	−3.38

*Rate of use per acre of major fertilizers: Calcium nitrate, 100 lbs.; triple superphosphate, 100 lbs.; muriate of potash, 120 lbs.
†Unfertilized check by farm land.

and net profit, was 60 pounds of boric acid an acre. On the College farm, yellow-top has been controlled with 20 to 30 pounds of borax.

FIG. 3.—Boron encouraged blooming and branching, as shown at left. Untreated alfalfa at right with yellow-top and blighted terminals. Willamette loam, 1937.

Borax contains 11.34% of the element boron, while boric acid contains 17.49%. Thus, 2 pounds of boric acid contains approximately the same amount of boron as 3 pounds of borax.

Recent stream-bottom soils and eastern Oregon types that are unleached or neutral in reaction have given little response to boron. Sandy soils, peat land, and aged soils are naturally low in boron. The liming of leached podsolic soils aggravates the deficiency.

An outline map of the state showing areas where response to boron has been obtained is shown in Fig. 4.

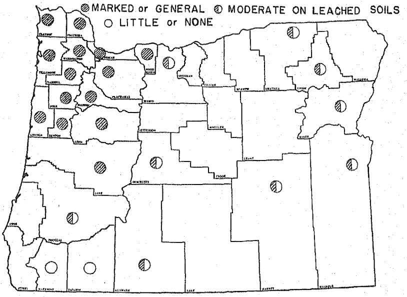


FIG. 4.—Oregon counties where boron deficiency has been recognized.

BORON CONTENT OF SOME OREGON SOILS AND ALFALFA

The soil analyses for boron was made by the hot water extraction method of Berger and Truog (1). The alfalfa samples, collected just before harvest in late summer, were ashed and total boron contents determined according to Berger and Truog.

The *alfalfa* samples from untreated plots in all cases showed yellow-top and contained 7.0 to 11.5 p.p.m. boron (Table 2). All boron-treated plots were fairly free from yellow-top and the boron content of these normal leaves was from 12.0 to 22.5 p.p.m. on plots without irrigation. It seems that little, if any, luxury consumption of boron occurs where the boron content of alfalfa is 20 p.p.m. Twenty p.p.m. is equivalent to 0.04 pound of boron or 0.35 pound of borax per ton of alfalfa. The boron content tended to increase with increasing amounts of boron applied (Fig. 5). Irrigation definitely increased the boron content of alfalfa, probably by increasing its availability or liberation, for the irrigation water contains only a very limited amount of this element. The increased moisture from irrigation could be expected to aid decomposition and thus liberation of boron from soil organic matter. Old stands of alfalfa and late season cuttings show more marked deficiency symptoms.

TABLE 2.—*Boron content of some Oregon soils and alfalfa.*

Treatment	Rate per acre, lbs.	Boron found, p.p.m.				
		In alfalfa	In soil			
			0–7 in.	7–20 in.	20–40 in.	40–50 in.
M. Davis Farm, Amity Silty Clay Loam						
Borax	45	16.0	0.83	0.70	0.28	0.30
Borax	30	13.0	0.90	0.48	0.33	0.45
Borax	15	13.0	0.75	0.50	0.25	0.30
Boric acid	45	12.0	0.95	0.60	0.45	0.45
Check	None	7.0	0.58	0.40	0.48	0.35
Hagg Bros. Farm, Willamette Silt Loam						
Borax	40	16.5	1.45	1.10	0.85	0.65
Check	None	6.5	0.70	0.90	0.60	0.55
Berger Farm, Willamette Silt Loam						
Borax	25	12.5	0.55	0.63	0.43	0.30
Check	None	9.0	0.45	0.35	0.38	0.20
Irrigated Plots 31–33, O. S. C. Farm, Willamette Silty Clay Loam						
Borax	30	38.0	1.60	1.35	0.65	0.50
Borax	20	28.5	0.65	0.48	0.40	0.38
Borax	10	27.0	0.50	0.48	0.48	0.42
Check	None	14.0	0.33	0.48	0.45	0.40
Unirrigated Plot 34, O. S. C. Farm, Willamette Silty Clay Loam						
Borax	30	23.5	—	—	—	—
Borax	20	13.0	—	—	—	—
Borax	10	11.5	—	—	—	—
Check	None	11.5	—	—	—	—

The *soil* analyses show that in these soils there is generally a larger amount of available boron in the surface soil than in the subsoil. This was not true of phosphoric acid soluble boron in the irrigation plots, as earlier reported by Powers (9). Nearly available boron appears to accumulate with organic matter in the surface soil horizons except perhaps in peat. Available boron in plots receiving 30 pounds or more of borax an acre, or its equivalent in boric acid, was found to be from 0.83 to 1.60 p.p.m. in the surface soil, notwithstanding the greater withdrawal by increased alfalfa yield. The Amity soil series has compact heavy subsoil with impeded drainage and yellow-top is more prevalent in alfalfa there than on the Willamette series. Based on yield tests, it may pay in some cases to use as much as 60 pounds of borax an acre on alfalfa.

BORON CARRIERS AND THEIR APPLICATION

The time preferred in western Oregon for application of borax is early spring before seeding or previous to renovating the alfalfa. However, some response has been obtained from spraying with a

weak solution of boric acid or from application before irrigation in midseason. Under semi-arid conditions, fall application appears to be preferable.

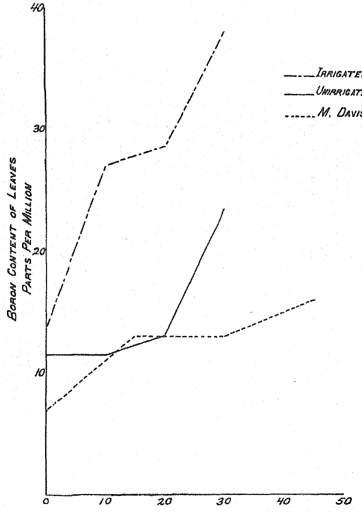


FIG. 5.—Relation of boron content of leaves to the rate of borax application.

Boric acid may be preferable to borax for plot trials on neutral soils or those of basic reaction. Leached acid soil that has been limed tends to "fix" boron in unavailable form. Where comparison was made on Amity silty clay loam, response from boric acid has been

more prompt than that from borax. However, borax will usually be cheaper and, in general, provides a satisfactory source of boron.

The economic rate of use of granular borax on alfalfa is some 30 to 60 pounds per acre. If alfalfa is to be left down 2 years or more and if yellow-top has occurred in dry weather, a 60-pound application would appear to be an economic rate, as shown in Table I. A comparable rate of use of boric acid would be two-thirds that amount. Retreatment where a little yellow-top is in evidence may be at half the initial application.

Application of granular borax may be accomplished by broadcasting on established alfalfa meadows with a cyclone or horn type of clover seeder. Borax may be mixed with landplaster or ordinary 20% superphosphate and then sown or drilled. Delayed or uneven application may result from attempts to apply borax with the first irrigation through sprinklers due to differences in pressure and distribution pattern. The range between favorable and toxic concentration of boron is small.

Duration of the treatment will vary with the climate, soil, crop yield, rate of application, and other factors. Boron applied may be removed by the plant, fixed by the soil in unavailable form, taken up by microorganisms, or leached away. Some yellow-top has reappeared the third season after a 20-pound application of boric acid or a 30-pound application of borax to Willamette silt loam. Four years after a 40-pound application of boric acid to Willamette silt loam scarcely a yellow alfalfa leaf could be found and soil analysis revealed the boron content was still above that of the check plots.

Slight gains in soil boron may come from ashes, 1 to 3 pounds of boron per ton, according to Midgley and Dunklee (7); manure, 0.02 pound of boron per ton, according to Melvin, *et al.* (6); unrefined fertilizers, 0.004 to 0.04%, according to Melvin, *et al.* (6); or other organic matter.

DISCUSSION

The alfalfa yield and boron content tend to parallel the available boron in the soil. Application of boron in the Willamette Valley has often meant the difference between a good crop and a poor one, especially during times of drouth, when a boron deficiency is most marked.

Results of plant and soil analyses indicate that a normal level of boron in alfalfa is on the order of 20 p.p.m., or more and that 1.0 p.p.m. of available boron in the surface soil should be sufficient to prevent the appearance of yellow-top as well as to give good yields.

Dennis and Dennis (3) list the following legumes as having responded to boron applications: Broad bean, garden pea, scarlet runner bean, kidney bean, soybean, crimson clover, red clover, white clover, alsike clover, sweet clover, lesser hop trefoil, sainfoin, white lupin, yellow lupin, common vetch, and hairy vetch. Ladino clover, crimson clover, red clover, and hairy vetch have shown indifferent response in Oregon.

The availability of boron in soils is influenced by a number of factors, including soil reaction, soil moisture content, active calcium content, and amount of soil organic matter present.

Boron increases the carotene and chlorophyll content of alfalfa (9), appears to give elasticity to cell membranes and to aid cell division (5), prevents swelling and blocking of roots (11), is important to nitrogen metabolism and aids development of nodules and nodule bacteria (2), and lessens the effect of drouth and improves the keeping qualities of fruit.[4]

Warington (13) found that boron prevents the breakdown of conducting tissues, and Johnston and Dore (5) learned that it affects carbohydrate translocation, pectin formation, and the amount of calcium in tissues. Observations by Powers (10) showed that boron promotes branching and blooming and aids longevity of alfalfa, while Eaton (4) reported that boron is essential for auxin formation in plants. Pollenization (12) and seed production (8) may be aided by boron.

SUMMARY

Boron deficiency symptoms of alfalfa are described and the boron contents of yellowed and normal alfalfa plants are compared to the supply of available boron in the soil. It is suggested that the amount of boron in normal alfalfa is above 20 p.p.m., while 1 p.p.m. of available boron seems to be the minimum desired for the surface 7 inches of soil in the Willamette Valley. Sandy soils, peat land, and aged leached soils are lowest in boron content and therefore show the most response to boron fertilizers. Most of the soils of the Willamette Valley and those west of the Coast range in Oregon seem to be low in boron, while some sandy leached soils irrigated with nearly pure water respond to boron applications in eastern Oregon.

The results of field trials with alfalfa and boron in the form of borax and boric acid are reported. Control of yellow-top has been effected with 30 pounds of borax per acre, but it may pay to use as much as 60 pounds per acre.

Boron may be applied to alfalfa meadows as granular borax and sown like clover seed at the rate of 30 to 60 pounds an acre. Fall application appears preferable in arid sections, while sowing in early spring if preferred in the humid section of Oregon where needed. A 30-pound application will be effective for about 3 years.

LITERATURE CITED

1. BERGER, K. C., and TRUOG, E. Boron determination in soils and plants, using the quinalizarin reaction. Ind. & Eng. Chem., Anal. Ed., 11:540–545. 1939.
2. BRENCHLEY, W. E., and THORNTON, H. G. The relation between the development, structure, and functioning of the nodules of *Vicia faba*, as influenced by the presence or absence of boron in the nutrient medium. Roy. Soc. (London) Proc., Ser. B. 98:No. B-691, 373–399. 1925.
3. DENNIS, A. C., and DENNIS, R. W. G. Boron and plant life, Part IV. The fert., feeding stuffs, and Farm Supplies Jour., Nov. 13 and 27, Dec. 11 and 24, 1940; Jan. 8 and 22, Feb. 5 and 19, 1941.
4. EATON, FRANK M. Interrelations in the effects of boron and indoleacetic acid on plant growth. Bot. Gaz., 101:700–705. 1940.
5. JOHNSTON, E. S., and DORE, W. H. Influence of boron on chemical composition and growth of tomato plants. Plant Phys., 4:31–62. 1929.

[4]Unpublished communication. 1938.

6. MELVIN, E. H., O'CONNOR, R. T., WULF, O. R., and KUNSMAN, C. H. Quantitative spectroscopic analyses of important trace elements in mixed fertilizers. Jour. Assoc. Off. Agr. Chem., 23:282–283. 1940.
7. MIDGLEY, A. R., and DUNCKLEE, R. E. Synthetic wood ashes require boron. Better Crops with Plant Food, 25:No. 5. 1941.
8. PILAND, J. R., and IRELAND, C. E. Application of borax produces seed set in alfalfa. Jour. Amer. Soc. Agron., 33:938. 1941.
9. POWERS, W. L. Boron as a fertilizer for western Oregon soils. Sci., 90:36–37. 1939.
10. ————. Boron, a minor plant nutrient of major importance. Better Crops with Plant Food, 25:No. 6. 1941.
11. SOMMER, A. L., and SOROKIN, H. Effects of the absence of boron and of some other essential elements on the cell and tissue structure of the root tips of *Pisum sativum*. Plant Phys., 3:237–260. 1928.
12. VASIL 'EV, YU. P. The significance of boron for the process of fertilization. Michurin. Plodovod., No. 4:24–32. 1937.
13. WARINGTON, R. The changes induced in the anatomical structure of *Vicia faba* by the absence of boron from the nutrient solution. Ann. Bot., 40: 27–42. 1926.

EFFICIENCY OF VARIOUS PHOSPHATE FERTILIZERS ON CALCAREOUS SOIL FOR ALFALFA AND SWEET CLOVER[1]

D. A. HINKLE[2]

NUMEROUS field trials (1, 2, 3, 4, 6, 7)[3] have shown that alfalfa responds remarkably well to phosphatic fertilizers when grown on the calcareous soils of the western states. Chemical analysis of these soils reveals that they are well supplied with total phosphorus, but that the amount which is available to the crop during the growing season is often very small. There is evidence (5) to indicate that the lack of solubility of the native soil phosphates in calcareous soils is due to the high lime content of these soils. Furthermore, soluble phosphatic fertilizers may revert to insoluble tricalcium phosphate by reacting with calcium present in the soil solution of these soils. However, this reversion apparently is not very rapid, as residual effects from applications of superphosphate on alfalfa have been observed from 2 to 3 years after the initial application (7).

The three principal materials now being used in New Mexico for the fertilization of alfalfa are treble superphosphate, containing 44 or 45% of available P_2O_5; ammonium phosphate, containing 11% of nitrogen and 48% of available P_2O_5; and the less concentrated grades of superphosphate, which may contain 16, 18, or 20% of available P_2O_5. In recent years several new phosphatic fertilizers have been made available for experimental purposes by the Tennessee Valley Authority. Among these new materials, triple superphosphate, which may contain as much as 50% of available P_2O_5, and calcium metaphosphate, containing 60 to 65% of available P_2O_5, seem promising as sources of phosphorus when applied to legumes grown on calcareous soils. The present information concerning the availability of calcium metaphosphate to plants grown on calcareous soils is somewhat conflicting.

McGeorge of Arizona (5) reports from Neubauer and from greenhouse studies that calcium metaphosphate is nearly as available as treble superphosphate or ammonium phosphate. Green (2), from field experiments on alfalfa in Montana, concludes that calcium metaphosphate is far less available than treble superphosphate. Toevs and Baker (7), working in Idaho, obtained significantly higher yields of alfalfa from treble superphosphate or TVA triple superphosphate than from calcium metaphosphate.

It is the purpose of the present report to present results of field and greenhouse experiments comparing several different phosphatic fertilizers as sources of phosphorus for alfalfa and annual yellow clover when grown on a calcareous soil.

---

[1]Contribution from the Department of Agronomy, New Mexico College of Agriculture and Mechanic Arts, State College, N. M. Published with the approval of the Director of the New Mexico Agricultural Experiment Station as Contribution No. 28. Received for publication June 5, 1942.

[2]Assistant Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 918.

MATERIALS AND METHODS

The field experiment was conducted on Gila clay soil. This soil consists of gray to grayish-brown clay, from 6 to 20 inches deep, underlain to a depth of 6 feet by irregularly stratified beds of sand, sandy loam, silt loam, and silty clay loam. Although this soil has a clay texture and is low in organic matter, it tends to be rather friable and remains in good tilth if properly handled. It occurs rather extensively throughout the irrigated valleys of southern Arizona and New Mexico. The experiment involved 30 plots, 27 feet wide and 150 feet long, which were planted to New Mexico-grown common alfalfa in the fall of 1939. The following treatments were replicated five times at random over the entire 30 plots:

No. 1...........135 lbs. of 44% superphosphate to the acre.
No. 2...........124 lbs. of Ammo-Phos 11–48–0 to the acre.
No. 3...........297 lbs. of 20% superphosphate to the acre.
No. 4........... 98 lbs. of 61% metaphosphate to the acre.
No. 5...........126 lbs. of TVA 47% superphosphate to the acre.
No. 6..........No fertilizer.

The correct amount of fertilizer for each plot was weighed out into paper bags and distributed by hand in the spring before active growth had started. The fertilizer treatments were applied each year by top dressing which is the generally accepted method of application used in the Southwest. The rates of application were calculated so as to supply approximately the same quantity of P_2O_5 for each treatment, namely, 60 pounds to the acre.

Hay samples were taken during the 3 years of the field experiment in order to determine if the fertilizer treatments had had any effect on the phosphorus content of the hay. The samples were taken by walking over the plots immediately after cutting and taking six small handfuls at random. These samples were then air-dried, ground, and stored for analysis. Samples were taken for the second, third, and fourth cuttings, only, in 1939, and for all five cuttings in the other two years. The air-dried hay contained approximately 6.5% moisture. The analysis for phosphorus was made by a slight modification of the official volumetric method of the Association of Official Agricultural Chemists. Duplicate determinations were made in all cases.

The greenhouse experiment consisted of growing annual yellow clover, *Melilotus indica*, in pots of Gila clay soil. The pots were 1-gallon, glazed, earthen pots, holding about 4½ kilograms of soil. The soil had not received any fertilizer in recent years and was deficient in available phosphorus. The following treatments were replicated three times:

No. 1...........Check.
No. 2...........124 lbs. of Ammo-Phos 11–48 to the acre.
No. 3...........135 lbs. of 44% superphosphate to the acre.
No. 4...........135 lbs. of 44% superphosphate plus 69 lbs. of ammonium sulfate to the acre.
No. 5........... 98 lbs. of calcium metaphosphate to the acre.
No. 6...........135 lbs. of 44% superphosphate plus 5 tons of manure to the acre.

Again the rates of application were so calculated as to apply the same amount of phosphorus in each treatment. The amounts of fertilizer for each treatment were weighed out and mixed with the upper 2 inches of the soil in the pots. In treatment No. 4, enough ammonium sulfate was included to contain the amount

of nitrogen added in Ammo-Phos in treatment No. 2. This was done in order to have a better basis for comparing the availability of the two sources of phosphorus. The manure used in treatment No. 6 contained 1.08% of nitrogen and 0.76% of total P_2O_5. Stands were thinned to 15 plants per pot and the soil was brought to optimum moisture twice each week.

RESULTS

FIELD TEST

Yields were not recorded for the first cutting of hay in 1939, since volunteer small grain came up in some of the plots in the spring. As a result, data for only four cuttings are presented for that year in Table 1, which also gives the yields for these treatments in 1940 and 1941.

TABLE 1.—*Yields of alfalfa hay on Gila clay field plots with various phosphate fertilizers.*

Fertilizer treatment	Yields in tons per acre			Average for 1940 and 1941, tons
	1939*	1940	1941	
44% superphosphate	4.58	7.84	7.51	7.68
Ammo-Phos 11-48-0	4.82	8.06	8.01	8.04
20% superphosphate	4.39	7.95	7.62	7.79
61% metaphosphate	4.11	7.01	7.47	7.24
47% triple superphosphate	4.52	7.86	7.98	7.92
No phosphate (check)	3.66	5.42	4.65	5.04
Least significant difference (odds 19:1)	0.56	0.91	0.84	0.84

*The yield data for 1939 were for four cuttings only, while those for 1940 and 1941 were for five cuttings.

A statistical study of the yield data was made by the analysis of variance method, and the least significant difference is given at the bottom of each column in the table. All fertilizer treatments yielded significantly higher than the check treatment for the 3 years' results. However, there was no significant difference between the yields of any of the other fertilizer treatments, except that Ammo-Phos yielded significantly higher than the calcium metaphosphate. These results would indicate no more availability for ammonium phosphate than for superphosphate, and the gypsum, which is contained in the less concentrated grades of superphosphate, was of no benefit to alfalfa grown on this calcareous soil. While the yield for the calcium metaphosphate treatment was lowest of all of the phosphatic fertilizers, yet it was not significantly lower, except in comparison with the yield for the Ammo-Phos treatment, which yielded the highest of all of the treatments. These results would indicate that calcium metaphosphate is reasonably available to alfalfa when grown on this soil type.

The results of the phosphorus analyses are given in Table 2. These results are expressed in terms of percentage of P_2O_5 in the air-dried hay. This hay contained on the average 6.5% of moisture.

TABLE 2.—*Phosphorus content of alfalfa hay fertilized with various phosphates.*

Fertilizer treatment	Percentage phosphoric acid (P_2O_5) content of hay			
	1939*	1940	1941	Average
44% superphosphate	0.487	0.465	0.452	0.468
Ammo-Phos 11–48–0	0.517	0.524	0.480	0.507
20% superphosphate	0.493	0.476	0.451	0.473
61% metaphosphate	0.457	0.456	0.437	0.450
47% triple superphosphate	0.497	0.538	0.482	0.506
No phosphate (check)	0.406	0.361	0.346	0.371
Least significant difference (odds 19:1)	0.024	0.021	0.036	0.032

*The data for 1939 are averages for three cuttings only; for the other 2 years they are averages for five cuttings.

Inspection of the data in Table 2 will show that fertilization of alfalfa with phosphatic fertilizer increased the phosphorus content of the hay. The greatest increase was for the hay from the Ammo-Phos plots, which averaged 36.6% higher in phosphorus than that from the check plots. The 3-year average phosphorus content of the hay from all of the fertilized plots was significantly higher than that from the check plots. The hay from the plots which received triple superphosphate and Ammo-Phos was significantly higher in phosphorus when compared with that from the other phosphate treatments, and the hay which received calcium metaphosphate was lowest in phosphorus content.

POT TEST

The results of the greenhouse experiment are presented in Table 3. It is quite evident from the amount of dry weight produced and the total amount of phosphorus absorbed by the clover which received calcium metaphosphate in comparison with the dry weight and amount of phosphorus absorbed by the plants which received other

TABLE 3.—*Yields of and phosphorus absorption by annual yellow clover grown in pots on Gila clay soil fertilized with various phosphates.*

Treatment	Yield, dry weight, grams	P_2O_5 in plants, %	Total P_2O_5 absorbed, gram	Recovery of phosphorus added, %
Check, no fertilizer	2.87	0.397	0.0114	——
Ammo-Phos 11–48–0	15.95	0.378	0.0604	36.06
Superphosphate 0–44–0	16.08	0.352	0.0566	33.26
Superphosphate 0–44–0 plus ammonium sulfate	17.07	0.360	0.0615	36.87
Calcium metaphosphate 0–61–0	12.92	0.372	0.0481	27.01
Superphosphate 0–44–0 plus manure	17.80	0.446	0.0794	22.04
Least significant difference (odds 19:1)	0.97			

forms of phosphatic fertilizers that this fertilizer is not so available to clover on this type of soil as the more common phosphates. It can been seen by inspection of Fig. 1 that the clover plants in treatment No. 5, which received calcium metaphosphate are not as large as those which received other phosphates. By comparing the plants of the check treatment, No. 1, with those of the other treatments, all of which received phosphates, it is evident that this soil is low in available phosphorus.

There was no significant difference in the yields from the Ammo-Phos and treble superphosphate treatments, and this agrees with the field experiment already described. However, when the superphosphate treatment was supplemented with ammonium sulfate, the yield was significantly higher than from superphosphate alone or from Ammo-Phos. The reason for this behavior is not apparent as the roots of the clover plants were well inoculated.

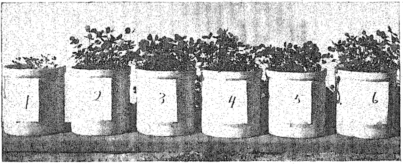


FIG. 1.—Clover plants 6 weeks after planting on Gila clay fertilized as follows: (1) check, (2) Ammo-Phos, (3) treble superphosphate, (4) treble superphosphate plus ammonium sulfate, (5) calcium metaphosphate, and (6) treble superphosphate plus manure.

Fertilization with the different phosphatic materials at the rate used did not appreciably alter the phosphorus content of the clover. In fact, the unfertilized plants were slightly higher in phosphorus than those receiving phosphates, except for those receiving both superphosphate and manure in which case the phosphorus absorbed is much higher for the plants receiving phosphates than for the check plants.

In calculating the percentage of phosphorus recovered, which is given in the last column of Table 3, it was assumed the excess amount of phosphorus in the plants from any of the treatments receiving phosphates over that in the plants receiving no phosphates came from the addition. Due allowance was made for the phosphorus contained in the manure. The small percentage of phosphorus recovered in the treatment in which superphosphate and manure were added together probably was due to the fact that not all of the organic phosphorus contained in the manure was mineralized during the experiment and therefore did not become available to the plants.

SUMMARY

Results of field tests comparing treble superphosphate, 20% superphosphate, Ammo-Phos (11-48-0), TVA triple superphosphate, and TVA metaphosphate as sources of phosphorus for alfalfa grown on Gila clay, an alkaline calcareous soil occurring in the irrigated valleys of the Southwest, showed that there was no significant difference in the yields from plots receiving treble superphosphate, TVA triple superphosphate, Ammo-Phos 11-48-0, and 20% superphosphate. However, the Ammo-Phos 11-48-0 did yield significantly more hay than calcium metaphosphate.

Fertilization with phosphates significantly increased the phosphorus content of the hay in all cases, the fertilized hay containing on an average about one-third more phosphorus than the unfertilized hay.

In a greenhouse experiment using the same soil type, annual yellow clover failed to produce as much dry weight or to absorb as much phosphorus from calcium metaphosphate as it did from Ammo-Phos (11-48-0) or treble superphosphate.

Application of nitrogen as ammonium sulfate slightly increased the absorption of phosphorus from superphosphate by clover in spite of the fact that the roots were inoculated.

LITERATURE CITED

1. Burke, E., Nygard, I. J., and Martin, W. McK. Experiments with phosphate fertilizers on Montana soils. Mont. Agr. Exp. Sta. Bul. 180. 1933.
2. Green, J. R. Phosphate investigations on irrigated crops, 1937. Mont. Agr. Exp. Sta. Bul. 356. 1938.
3. Hinkle, D. A. Use of phosphatic fertilizer on alfalfa. N. M. Agr. Exp. Sta. Bul. 289. 1942.
4. McGeorge, W. T., and Breazeale, J. F. Fertilization of alfalfa on alkaline calcareous soils. Ariz. Agr. Exp. Sta. Bul. 154. 1936.
5. ————. Factors influencing the availability of native soil phosphate and phosphate fertilizers in Arizona soils. Ariz. Agr. Exp. Sta. Tech. Bul.
6. Pittman, D. W. Effect of manure and of phosphorus fertilizer on the yield and composition of alfalfa hay. Utah Agr. Exp. Sta. Bul. 247. 1934.
7. Toevs, J. L., and Baker, G. O. Progress report of phosphate and other fertilizer investigations at the Aberdeen Branch Experiment Station, University of Idaho. Ida. Agr. Expt. Sta. Bul. 230. 1939.

PLOT TECHNIC STUDIES WITH NAVY BEANS[1]

E. E. DOWN AND J. W. THAYER, JR.[2]

THE studies reported herewith deal with the width of plot necessary for navy beans to overcome the competitive effect of contrasting rates of seeding or varieties planted in contiguous plots.

MATERIALS AND METHODS

All plantings were made in a north-south direction, rows 28 inches apart, planted 32 feet long and trimmed to 30 feet in length shortly before harvest. Ordinary nursery equipment was used for planting and harvesting. At harvest the rows were pulled and immediately stacked in small stacks using a small amount of straw between the rows in the stack to prevent mixing.

Two treatments, both planted each year 1937–41,[3] were used:

Treatment A.—Rate of seeding. Plots planted alternately to heavy (75 pounds) and light (20 pounds) rates of seeding of the Michelite variety of navy beans.

Treatment B.—Variety competition. Plots planted alternately to the Robust and Michelite varieties of navy beans. Both varieties were sown at the rate of 45 pounds of beans per acre.

The alternate system of planting was used throughout each treatment so that all plots would always have the same contrasting plots on both sides. Care was taken to add border plots of the proper treatment wherever they were necessary to fulfill the requirements of the experimental layout.

Plot widths of one, three, and five rows were included in both treatments. As 10 replications were used, the total number of plots per treatment was 60, i.e., 2 (rates of seeding or varieties) $\times$ 10 (replications) $\times$ 3 (plot widths). The total number of rows harvested per treatment was 180, i.e., 2 (rate of seeding or varieties) $\times$ 10 (replications) $\times$ 9 (1 + 3 + 5 rows per plot).

NOMENCLATURE

Certain designations are used to simplify the discussion. If two or more rows are involved, it is understood that their mean yield was used.

One row plot:	1_1 single row
Three row plot:	3_1 center row
	3_2 (o) two outside border rows
	3_3 all three rows
Five row plot:	5_1 center row
	5_2 (s) two second border rows
	5_3 three center rows
	5_2 (o) two outside border rows
	5_5 all five rows

[1]Contributions from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 591 (New Series). Received for publication June 8, 1942.

[2]Research Professor and Research Assistant in Farm Crops.

[3]Unfavorable weather destroyed the bean plots in 1940.

RESULTS

It is clearly shown by the data (Table 1) that the border rows of the low-yielding plots are depressed by having high-yielding plots grown contiguous to them. In treatment A, the heavily seeded plots on the average outyielded the light-seeded plots in all instances, and the border rows of the light-seeded plots were depressed materially in comparison with their corresponding inner rows by competition from the adjacent heavily seeded rows. While the yields of the border rows of the low-yielding plots were depressed by this competition, the yields of the border rows of the adjoining high-yielding plots were increased. When such competition exists, a comparison of the yields from the whole plots gives a lower percentage comparison than that obtained from yields of central plot portions. The differences between yields are materially increased since the yields from the high-yielding plots are higher and those from the low-yielding plots lower than they should be.

TABLE 1.—*A comparison of the 4-year average yields of the several portions of the one-, three-, and five-row plots.*

Plot portion	Heavy (75 lbs.), grams	Light (20 lbs.), gram	Difference, grams	Comparative yields light/heavy, %
		Treatment A		
1_1	1,074.3	856.9	217.4	79.8
3_1	1,019.6	992.2	27.4	97.3
3_2 (o)	1,043.4	942.6	100.8	90.3
3_3	1,035.3	954.1	81.2	92.1
5_1	1,080.4	1,032.6	47.8	95.6
5_3	1,074.8	1,041.5	33.5	96.9
5_2 (o)	1,099.9	987.5	112.4	89.8
5_5	1,084.8	1,023.3	61.5	94.3
		Treatment B		
Plot portion	Robust, grams	Michelite, grams	Difference, grams	Comparative yields M/R, %
1_1	986.8	866.0	120.8	87.8
3_1	976.3	976.9	0.6	100.1
3_2 (o)	994.0	951.7	42.3	95.7
3_3	986.1	960.0	26.1	97.3
5_1	1,043.1	1,039.1	4.0	99.6
5_3	1,046.5	1,046.3	0.2	100.0
5_2 (o)	1,057.1	1,048.6	8.5	99.2
5_5	1,050.6	1,047.2	3.4	99.7

The distance into a plot that yields are modified by competition is shown by the relative yield percentages (last column Table 1). When the border rows are not included, the relative yields come to a maximum. In both treatments the maximum is reached in the three-row plots.

TABLE 2.—*The differences between the 4-year average yields of the outside border rows and their next inner rows.*

Difference between	Treatment A		Treatment B	
	Heavy (75 lbs.), grams	Light (20 lbs.), grams	Robust, grams	Michelite, grams
3_2 (o) -3_1	23.8	-49.6^*	17.7	-25.2
5_2 (o) -5_2 (s)	27.9	-48.0	9.0	-6.2
5_2 (s) -5_1	-8.4	2.9	5.0	25.7

*A negative sign shows that the yield of the inner row or rows was greater than that of the next outer row. A difference must be greater than 30 grams to exceed the 5% point of significance. No difference was obtained at the 1% point.

To show the specific influence of competition differences between (1) the yields of the outside border rows and their corresponding next inner rows and (2) the yield of the second border rows and the center row, the data in Table 2 are presented. Of the 12 differences only 2 are statistically significant. These are found in the first two cases for the light rate of seeding in treatment A. As in other crops where competition takes place, the yield of the border rows of the low-yielding plots is decreased more than that of the border rows of the high-yielding plots is increased.

These results show that even though competition was not great enough to cause statistically measurable difference, the inclusion of border rows in their plot yields helped to increase the spread between elements in a treatment. This increase is a statistically measurable difference except in plots five rows wide, treatment B (Table 1).

The question of how wide a plot to use for testing of navy beans to avoid differences due to competition is shown clearly in the data assembled in Table 3. The differences between varieties within a treatment are shown with the border rows eliminated. The yields of the one-row plot are so subjected to competition that they should not be used. In the case of treatment B this is true even though Robust and Michelite varieties are very similar in their general habit of growth and size of vine. Michelite blooms and ripens some 3 days earlier than Robust. It may be that this difference allows Robust to rob Michelite in the one-row plots of needed elements as Michelite is storing food in the cotyledons. In both treatments the center row

TABLE 3.—*The differences between the 4-year average yields of the two rates of seeding and of the two varieties.*

Plot portion	Treatment A	Treatment B
	Heavy-light rate, grams	Robust-Michelite, grams
1_1	217.4^*	120.8
3_1	27.4	-0.6
5_3	33.5	0.2

*A difference of 40 and 100 grams is necessary to exceed the 5% and 1% point of significance, respectively.

of the three-row plot is as satisfactory as the three center rows of a five-row plot. Also, it is quite evident (Table 1) that variations in yield due to large differences in rate of seeding of navy beans are almost entirely overcome by planting in three-row plots and harvesting the center row.

SUMMARY

Data collected from navy bean plots involving condition of severe competition between contiguous plots of different row widths during a 4-year period were analyzed. Under conditions of this experiment these data indicate that (1) in no case did the effects of competition extend beyond the outside border rows to a statistically significant amount; (2) in no case was a more satisfactory comparison obtained by including the border rows in the plot yields; (3) the three-row plot, discarding the border rows, was the maximum width needed to give an accurate comparison with navy beans; and (4) the yields of the one-row plot were so subject to competition that they should not be used for comparison purposes for navy beans.

GENERAL VS. SPECIFIC COMBINING ABILITY IN SINGLE CROSSES OF CORN[1]

G. F. SPRAGUE AND LOYD A. TATUM[2]

MODERN corn breeding methods involve the isolation of commercially acceptable inbred lines and their evaluation in hybrids. Top-cross (inbred×variety) and single-cross tests are used for this evaluation, usually after the lines have been self-pollinated for three or more generations. It has been suggested (4, 9)[3] that tests for combining ability could well be made at an earlier stage in the inbreeding process. Regardless of the amount of inbreeding at the beginning of the testing program, it is desirable to know the relative importance of general and specific combining ability. Also, it is important to know whether the methods of testing in general use differ in the type of gene action revealed.

The term "general combining ability" is used to designate the average performance of a line in hybrid combinations. Several investigators have reported data bearing on this point. Kiesselbach (5) found a general relation between the yield of inbred lines and of their hybrid combinations. Richey (6) and Richey and Mayer (7) found the performance of inbreds to be only casually related to that of their hybrids. Jenkins (3) has presented data indicating that combining ability, as measured by the top-cross test, is relatively stable and is influenced but little by selection during the inbreeding process.

Numerous investigators have reported on the correlation between various morphological characters of the inbred parents and the yielding ability of their resulting hybrids. None of these investigations, however, has provided an evaluation of the relative importance of general and specific combining ability.

The term "specific combining ability" is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Among animal breeders the term "nicking" has been used in the same general sense. Specific combining ability may result from several causes, such as Mendelian segregation and recombination, incorrect genotypic classification, and various types of factor interactions. With the procedures commonly used in the evaluation of inbred lines of corn the first two causes mentioned are probably of minor importance. In animal breeding the reverse is probably true. Seath and Lush (8) have reported that "nicking" as expressed in the

[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Journal paper (J-1006) of the Iowa Agricultural Experiment Station. Project 163. Received for publication June 13, 1942.

[2]Agronomist and Junior Plant Breeder, respectively, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 932.

milk production and butterfat percentage of dairy cows was not of sufficient importance to interfere with the proving of sires.

The present investigation is an attempt to compare the relative importance of general and specific combining ability in single-cross corn hybrids and to discuss the relation between testing procedures and combining ability.

The data from eight tests of single crosses were used. Of these, six were grown in 1940 and involved lines surviving previous selection and tests. The remaining two were grown in 1930 and involved lines which had not been closely selected for yielding ability.

Estimates of general (σ^2G) and specific (σ^2S) combining ability were obtained in the following manner:[4]

Two-way tables were prepared listing the means of the $\frac{n(n-1)}{2}$ crosses involving the n inbred lines (Table 1). Totals then were calculated for all crosses involving a particular line. These were designated Ta, Tb, etc. A grand total also was obtained for all crosses (T). The formula for obtaining the variance in general combining ability may be expressed in generalized terms as follows:

$$\sigma^2 Ga = \frac{n-1}{n(n-2)} \left[\left\{ \frac{(\frac{n}{2} Ta - T)^2}{\frac{n(n-1)(n-2)}{4}} \right\} - \frac{E}{r} \right]$$

where n is the number of parent lines involved, E is error mean square per plot, and r is the number of replications. Values for the σ^2G were obtained for each of the lines involved in each yield trial.

Estimates of the σ^2S were obtained in the following manner: The mean yield for each cross in the original table was multiplied by (n – 2). Then to eliminate differences in general combining ability these values were adjusted by the appropriate row and column totals as follows:

$$(n-2)\,(ab) - Ta - Tb + \frac{2}{n-1}\,T.$$

The resulting value can be either positive or negative and indicates whether the (ab) combination performed relatively poorer or better than would be expected on the basis of the average performance of the two parental lines. Similarly values are obtained for ac, ad, etc. The sum of the (a) terms should equal zero. The sum of the squares for (a) then is divided by (n – 2) (n – 3) to reduce it to a unit basis and by (n – 2) to get the mean square. The value so obtained is equal to $\frac{E}{r} + \frac{(n-3)\sigma^2 Sa}{(n-2)}$ (Table 2).

[4]The authors wish to acknowledge their indebtedness to Prof. W. G. Cochran for supplying the formulae used in the calculation of general and specific combining ability, and to Prof. J. L. Lush for many helpful suggestions.

TABLE 1.—*Yields in bushels per acre for 45 single crosses compared in experiment 27 (uniform midseason test) grown at Ames, Iowa, in 1941.*

	38–11	P 8	WF9	I159L1	L317	Hy	R4	OhO7	4–8	187–2	Total	Mean	σ^2G	σ^2S
38–11	—	85.6	83.6	97.8	97.5	92.0	91.9	96.5	81.2	88.3	814.4	90.5	13.1	16.2
P8	85.6	—	91.2	104.8	101.6	85.8	92.1	78.8	80.4	89.5	809.8	90.0	9.1	81.3
WF9	83.6	91.2	—	86.8	79.9	65.4	83.7	92.6	77.1	83.2	743.5	82.6	26.1	52.1
I159L1	97.8	104.8	86.8	—	97.4	99.5	100.6	96.7	91.2	79.9	854.7	95.0	75.7	40.0
L317	97.5	101.6	79.9	97.4	—	96.5	82.7	92.9	77.9	82.6	809.0	89.9	8.5	37.3
Hy	92.0	85.8	65.4	99.5	96.5	—	80.1	92.7	75.6	70.4	758.0	84.2	10.7	61.6
R4	91.9	92.1	83.7	100.6	82.7	80.1	—	90.2	74.1	72.1	767.5	85.3	4.1	23.8
OhO7	96.5	78.8	92.6	96.7	92.9	92.7	90.2	—	90.6	95.5	826.5	91.8	4.0	68.4
4–8	81.2	80.4	77.1	91.2	77.9	75.6	74.1	90.6	—	77.7	725.8	80.6	53.9	11.3
187–2	88.3	89.5	83.2	79.9	82.6	70.4	72.1	95.5	77.7	—	739.2	82.1	31.9	58.1
Total (45)											3,924.2	87.2		

$$\sigma^2\mathrm{G}\ (38\text{–}11) = \frac{9}{80}\left[\left\{\frac{(5 \times 814.4 - 3924.2)^2}{180}\right\} - 5.36\right] = 13.1.$$

TABLE 2.—*Illustration of procedures used in calculating the values for σ^2 S.*

	Actual yields × (n-2)									
	38–11	P8	WF9	I159L1	L317	Hy	R4	07	4–8	187–2
38–11	—	684.8	668.8	782.4	780.0	736.0	735.2	772.0	649.6	706.4
P8	684.8	—	729.6	838.4	812.8	686.4	736.8	630.4	643.2	716.0
WF9	668.8	729.6	—	694.4	639.2	523.2	669.6	740.8	616.8	665.6
I159L1	782.4	838.4	694.4	—	779.2	796.0	804.8	773.6	729.6	639.2

To adjust for row and column totals of Table 1

$$n-2(ab)-Ta-Tb+\frac{2}{n-1}T \text{ or}$$

$$684.8-814.4-809.8+872.0= -67.4$$

38–11	—	−67.4	−17.1	−14.7	28.6	35.6	25.3	3.1	−18.6	24.8
P8	−67.4	—	48.3	45.9	66.0	−9.4	31.5	−133.9	−20.4	39.0
WF9	−17.1	48.3	—	−31.8	−41.3	−106.3	30.6	42.8	19.5	54.9
I159L1	−14.7	45.9	−31.8	—	−12.5	55.3	54.6	−35.6	21.1	−82.7

$$(-67.4)^2+(-17.1)^2+(-14.7)^2 \text{ etc} = 8747.28$$

$$8747.28 \div 448 = 19.53$$

$$\sigma^2 Sa \frac{n-3}{n-2} + \frac{E}{r} = 19.53$$

$$\sigma^2 Sa = 16.19$$

Average values which are functions of σ^2G and σ^2S can be obtained by a somewhat simpler approach. The 45 yield values listed in Table 1 can be handled by a simple analysis of variance technic. The variance associated with the differences between group means is the mean σ^2G before it has been freed from the error and specific combining ability components. Similarly, the mean square for within groups is an estimate of the mean σ^2S plus the error component. The limitation of this simpler approach lies in the fact that it is impossible to evaluate the σ^2G and σ^2S for the individual lines involved in the test.

It should perhaps be emphasized that the estimates of the σ^2S and σ^2G so obtained are relative and dependent upon the particular group of lines involved in the hybrids under test. The relative differences in performance may be interpreted in terms of genes and gene action. When the estimates of the σ^2G are low, it indicates that that particular line is average in its general combining ability. Large values for σ^2G may arise because a particular line is either much better or much poorer than the remaining lines with which it is compared. Thus it provides an indication of the importance of genes which are largely additive in their effects.[5]

Low values for the σ^2S indicate that hybrids involving this particular line have performed as would be expected on the basis of their

[5]The customary statistical procedure is to consider as dominance deviations only the discrepancies between the additive scheme which will best fit the population and the actual facts. Thus the average dominance contribution of a line is partly included in the additive gene effects. There is as yet no satisfactory statistical procedure for separating dominance and epistatic effects for data of the sort used in this study.

general combining ability. High values for σ^2S indicate that some combinations did relatively better and others poorer than expected. Specific combining ability thus is largely dependent on genes with dominance or epistatic effects.

EXPERIMENTAL RESULTS

Estimates of the σ^2G and σ^2S from six tests of single crosses are presented in Table 3. Experiment 20, the uniform test of early single crosses, was grown near Leland, Iowa. The lines involved all had been tested previously and were known to have good combining ability. The lines A, CC26, and CC27 had the largest values for σ^2G. CC26 had the lowest and CC27 had the highest average yield of the nine lines included. The estimates of specific combining ability (σ^2S) are larger than general combining ability in every case indicating that for this group of lines epistatic and dominance effects are much more important than additive gene effects.

Experiment 18 involved 12 early lines tested in single-cross combinations at Sheldon, Iowa. In one instance the σ^2G is greater than the corresponding estimate of the σ^2S. The line involved, Y56, had the highest average yield of all lines included in this test. CC5 and CC7 also have large values for σ^2G. In the case of CC5 the estimates of both general and specific combining ability were large. This line was quite susceptible to stalk breaking in several of its combinations. Stalk breaking occurred early and so had a pronounced effect on yield. The average yield of this line in all combinations was low which accounts for the large value for the σ^2G. Certain combinations had sufficient stalk strength so that little lodging occurred. The failure of these combinations to perform similarly to the remaining CC5 crosses resulted in a large σ^2S value. CC7 had a large σ^2G value due to the high average yield of its hybrid combinations. For this experiment σ^2S is over twice as great as σ^2G.

Experiments 25 and 26 were duplicates, 25 being grown at Ames and 26 at Davenport, Iowa. The strain×location interaction was significant for these two locations, indicating that at least some of the single crosses differed in their yield responses at the two locations. This difference in response is reflected in the lack of agreement in the estimates of σ^2G and σ^2S obtained from the two tests. In both tests the σ^2G for L 317 exceeds the σ^2S. This is in agreement with the known high average combining ability of this line. In general the σ^2G values are higher for the Davenport than for the Ames test. Epistatic and dominance effects were about three times as important as additive effects for the Ames test whereas epistatic and dominance effects were essentially equal to additive gene effects for the Davenport test. The majority of the lines involved were selected and the preliminary tests for hybrid combining ability made at Ames, which may account for the differences obtained.

Experiments 27 and "A" were from the uniform midseason tests, 27 being grown at Ames and "A" at Lafayette, Indiana. Yield responses were quite different at the two locations. Combinations involving I 159L1 were highest and 4–8 combinations lowest in yield

TABLE 3.—*Estimates of the relative importance of general (σ^2G) and specific (σ^2S) combining ability from single-crosses involving previously tested inbred lines.*

Exp. No.	Location	Variance	Inbred lines involved											
20	Leland		Oh4OB	Oh51A	CC24	CC25	CC26	CC27	A	Fe	I234			
		G	0.0	2.8	1.1	0.5	13.3	8.3	9.6	4.2	2.5			
		S	37.5	9.4	3.2	19.6	18.4	68.9	49.1	17.8	15.7			
18	Sheldon		Oh4OB	Y46	Y56	Y63	Y82	St665	AR5	Fe	CC5	CC7	G28	M14
		G	11.9	4.1	15.1	11.4	0.0	0.0	3.9	0.5	90.7	18.5	0.1	0.9
		S	18.2	31.9	5.0	56.6	14.0	13.4	36.9	32.7	99.1	27.1	24.8	16.3
25	Ames		I159	I198	I224	L289	L317	540	R4	Hy	WF9	38–11		
		G	0.0	0.0	31.2	0.1	61.7	1.2	0.0	5.1	6.9	0.0		
		S	60.6	9.0	46.9	42.1	46.4	55.1	51.5	44.4	73.0	73.1		
26	Davenport		I159	I198	I224	L289	L317	540	R4	Hy	WF9	38–11		
		G	160.7	7.6	3.7	21.5	101.2	0.0	0.1	21.7	0.6	0.0		
		S	38.9	27.5	24.7	41.1	24.6	14.6	45.7	21.7	60.1	18.3		
27	Ames		I159L1	P8	4–8	187–2	L317	O7	R4	Hy	WF9	38–11		
		G	75.7	9.1	53.9	31.9	8.5	4.0	4.1	10.7	26.1	13.1		
		S	40.0	81.3	11.3	58.1	37.3	68.4	23.8	61.6	52.1	16.2		
A	Indiana		I159L1	P8	4–8	187–2	L317	O7	R4	Hy	WF9	38–11		
		G	10.8	0.0	0.0	0.0	5.9	5.0	0.8	0.0	18.8	11.7		
		S	0.0	29.9	15.8	5.8	0.0	11.0	12.0	5.3	4.4	35.6		

at both locations, but the ranking of the remaining combinations differed widely. At Ames only the I 159L1 and 4–8 combinations had values of σ^2G which were greater than the corresponding σ^2S. In yield the I 159L1 combinations average 8.7 bushels per acre more than all other crosses taken as a group, whereas the 4–8 combination produced the lowest average yield. Crosses involving the line P8 ranged from the highest to nearly the lowest in yield which accounts for the large σ^2S value. The σ^2S for the O7 combinations was only slightly lower. While the average performance of all O7 combinations was high, a definite interaction was indicated by the fact that its response in some combinations was quite different than most of the remaining lines.

The results from these six single-cross tests indicate that specific combining ability is more important than general combining ability in influencing yield. The lines involved all had been tested previously for combining ability by either top-cross or single-cross tests. On the basis of such tests, lines with low combining ability would be discarded, the lines remaining then would represent only the higher yielding portion of the frequency distribution. Thus, because of the selection practiced, variation with respect to average performance in hybrid combinations has been largely eliminated. To test this possibility estimates of σ^2G and σ^2S were calculated for two single-cross tests grown at Ames in 1930 which involved relatively unselected lines. The results are presented in Table 4.

The contrast between the two groups of material (1940 and 1930) is rather striking. In both of the 1930 tests the σ^2G is considerably larger than the σ^2S. This indicates that with untested material additive effects are more important than epistatis and dominance effects.

To determine whether a similar relationship would hold for characteristics other than yield, estimates of the σ^2G and σ^2S were determined for lodging in experiments 1 (1930) and 27 (1940). In experiment 1 involving lines previously unselected, the average σ^2G was over three times the corresponding σ^2S. In experiment 27, which involved tested lines, the σ^2S was about 10% greater than the σ^2G.

The results presented have definite implications as to plant breeding technics and genetics. In the evaluations of inbred lines, it has been a rather common practice to test in top-cross combinations after three to five generations of selfing. This provides a preliminary basis for discarding the less desirable material. Tests of single and double crosses follow with only a very small percentage of the original lines surviving all tests and being eventually released for commercial production.

Jenkins (2) has presented data, indicating that double-cross performance as predicted from top-cross data was somewhat less accurate then predictions from single-cross tests. Some investigators have relied almost wholly on top-cross data for evaluating lines. Others have been somewhat disappointed in top-crossing as a method of testing and have suggested that such tests might well be discontinued, relying solely on single-cross performance tests as a basis for elimination. Jenkins' data were obtained from yield tests conducted in 1930 and involved lines with little previous testing. This would account for the results he obtained.

TABLE 4.—*Estimates of the relative importance of general (σ^2G) and specific (σ^2S) combining ability from single-crosses involving inbred lines not previously tested.*

Exp. No.	Variance	Inbred lines involved										
1		4Co11	4Co13	4Co20	4Co27	4Co31	4Co56	4Co63	4Co82	4Co101	SK111	WhF619
	G	20.9	2.8	42.0	94.0	49.3	0.0	18.7	48.1	64.3	2.0	0.0
	S	22.8	12.9	20.6	5.1	31.1	6.6	11.1	19.4	17.8	4.5	12.5
2		I197	I230	I238	B1351	Pr364	KB394	KB397	Os420	Os440	WD456	H700
	G	26.9	147.5	17.8	2.9	17.3	38.9	197.8	11.6	48.5	97.7	11.3
	S	38.5	22.1	10.1	61.5	29.1	58.1	17.7	49.1	41.6	42.0	25.8

From the results reported here it appears that an intermediate practice would be preferable to either extreme. From the standpoint of efficiency the top-cross test should be used primarily for the preliminary evaluation of lines on the basis of their general combining ability. That top-cross tests are quite effective in accomplishing this purpose is indicated by the low σ^2G values obtained in this study with lines previously tested for general combining ability.

Single-cross tests, on the other hand, are most satisfactory when their main purpose is to determine the most promising specific combinations. Such tests also reveal differences in general combining ability, but the major elimination on this basis can be done most economically with top-cross tests.

The results here reported also have a direct bearing on the early testing of new lines. Stocks chosen for the tester parent should provide a sufficiently broad base of genetic diversity to insure that differences in yields are due primarily to differences in general combining ability. Beard (1) has suggested that a highly heterozygous single cross would be a desirable tester parent. While such a cross would undoubtedly possess many factors affecting general combining ability, it would also contain factors with strong dominance and epistatic effects. To this extent, the evaluation of tested lines might be influenced by specific combining ability to a greater extent than would be desirable. Insufficient data are available to judge the importance of this possible limitation. Until adequate data are accumulated a safer procedure would be to use two or more single or double crosses as tester parents. If testing facilities are limited, the crosses on the different testers could be bulked for the yield trials. This would tend partially to eliminate specific combining ability from influencing the average performance of any given line.

The data presented in Tables 3 and 4 furnish a basis for comparing the relative frequency or importance of genes having additive as contrasted with dominance and epistatic effects. In a population of lines unselected for combining ability, genes with additive effects (general combining ability) are either more common or produce greater effects than genes with dominance or epistatic effects.

In previously selected material, genes with dominance and epistatic effects are more important than genes with additive effects. This is true only because the lines remaining from previous elimination trials have a much higher degree of similarity in performance than the original population. Since differences in additive effects (average combining ability) have been largely eliminated, dominance and epistatic effects become relatively more important.

SUMMARY

A method is presented for evaluating the relative importance of genes contributing to general and specific combining ability in the yield of single crosses of corn.

In single crosses involving previously tested lines, genes conditioning specific combining ability have the most effect in determining yield differences.

In previously untested material, genes affecting general recombining ability are of most importance.

The bearing of these findings on testing technics is discussed.

LITERATURE CITED

1. BEARD, D. F. Relative values of unrelated single crosses and an open-pollinated variety as testers of inbred lines of corn. Doctoral Dessertations No. 33:9–16. Ohio State Univ. Press: Abs. 1940.
2. JENKINS, MERLE T. Methods of estimating the performance of double crosses in corn. Jour. Amer. Soc. Agron., 26:199–204. 1934.
3. ———. The effect of inbreeding and of selection within inbred lines of maize upon the hybrids made after successive generations of selfing. Iowa State College Jour. Sci., 9:429–450. 1935.
4. ———. The segregation of genes affecting yield of grain in maize. Jour. Amer. Soc. Agron., 32:55–63. 1940.
5. KIESSELBACH, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bul. 20. 1922.
6. RICHEY, F. D. Effects of selection on the yield of a cross between varieties of corn. U. S. D. A. Bul. 1209. 1924.
7. ———, and MAYER, L. S. The productiveness of successive generations of self fertilized lines of corn and of crosses between them. U. S. D. A. Bul. 1354. 1925.
8. SEATH, D. M., and LUSH, JAY L. Nicking in dairy cattle. Jour. Dairy Sci., 23: 103–113. 1940.
9. SPRAGUE, G. F. An estimation of the number of top-crossed plants required for adequate representation of a corn variety. Jour. Amer. Soc. Agron., 31: 11–16. 1939.

THE MINERAL CONTENT OF VARIOUS CLONES OF WHITE CLOVER WHEN GROWN ON DIFFERENT SOILS[1]

R. R. ROBINSON[2]

A NUMBER of investigators have reported that different plants of the same species may vary widely in percentage mineral content when grown under identical conditions of soil and climate. Whether or not relative differences in composition are maintained when the plants are grown under widely different conditions has received less consideration.

Fort and McKaig (3)[3] grew different varieties of sugar cane on a number of sandy loam soils with a uniform fertilizer treatment and concluded that different varieties grown under uniform conditions maintained their relative differences in percentage calcium, phosphorus, potassium, and certain other elements.

Woodford and McCalla (6) sampled two varieties of wheat at five stages of maturity on two widely different soils, a black one and a gray one, and concluded that one variety was higher than the other in nitrogen when grown on the black soil, and in ash, phosphorus, and potassium when grown on the gray soil.

The primary objective of this investigation was to determine if clones of white clover, *Trifolium repens* L., that differed in percentage of calcium, phosphorus, and potassium when grown on one soil maintained those relative differences when grown on other soils.

EXPERIMENTAL PROCEDURE

For this investigation eight selected clones of white clover were grown on each of five soils in the greenhouse. These clones had shown marked differences in percentage calcium and phosphorus and in calcium-phosphorus ratios in preliminary trials on a Dekalb soil in the greenhouse. The five soils, described briefly

TABLE 1.—*Descriptions of the soils used in the experiment.*

Soil type	Source of soil*	pH value†	Soluble phosphorus, lbs. per acre‡	Available potassium§
Dekalb silt loam........	Pa.	6.45	33	Medium-high
Hagerstown silt loam...	Pa.	6.25	77	High
Charlton silt loam......	Maine	5.85	57	Medium
Webster loam..........	Iowa	6.10	173	Low
Cecil clay loam.........	S. C.	5.30	21	Medium

*The writer wishes to express his appreciation to the following men for furnishing soil samples from their respective states: Dr. D. S. Fink, Maine; Dr. W. H. Pierre, Iowa; and Dr. W. R. Paden, South Carolina.
†Determined by a glass electrode on a 1-1 soil-water suspension.
‡Determined by Truog's method (5).
§Estimated from the yield and mineral content of the crop.

[1]Contribution No. 37 of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the northeastern states experiment stations. Received for publication June 18, 1942.

[2]Associate agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 939.

in Table 1, represent four of the great soil groups, namely, the brown podzolic, the gray-brown podzolic, the red podzolic, and the prairie. Except for the Dekalb, they had received no lime or fertilizer in recent years. The Dekalb soil was treated with lime and phosphate because previous trials had shown that the untreated soil would not grow a crop of clover.

For the experiment 1-gallon pots were used and were arranged at random in the three replications in a "split-plot" design with the soils constituting the main plots and the clones the sub-plots. Five well-rooted cuttings were started in each pot on November 10 and the plants were harvested on February 9. During this period, Mazda light at an intensity of about 100 foot-candles was supplied to increase the daylength to 13 hours. None of the clones flowered during this period, so that the material harvested consisted entirely of leaflets and petioles. Yields of dry matter and the percentages of calcium, phosphorus, and potassium were determined.

For the chemical determinations the plant material was ashed at 1,100° F, the ash dissolved in hydrochloric acid, silica dehydrated by the usual procedure, and the silica-free ash dissolved in dilute hydrochloric acid. The solution was made to volume and aliquots used for the determination of calcium, phosphorus, and potassium. Calcium was determined essentially by the method of Kramer and Tisdall (4), phosphorus by the method of Fiske and Subbarow (2), and potassium by the method of Brown, Robinson, and Browning (1).

EXPERIMENTAL RESULTS

YIELDS OF DRY MATTER

The data in Tables 2 and 3 show highly significant differences in yields of dry matter due to both clones and soils. On each of the five soils, clone 1 produced higher yields of dry matter than any other clone; clones 2, 3, and 4 also gave relatively high yields on each soil; clones 5 and 6 were definitely poorer; and clones 7 and 8 produced the lowest yields of dry matter. In general, the relative differences in yields of the various clones were maintained on each of the five soils. On the fertile soils, however, the actual differences in yields of dry matter between the high-yielding clones and the low-yielding ones were greater than on the poor soils.

TABLE 2.—*The yields of various clones of white clover when grown on different soils.*

Soil	Yields of dry matter, grams per pot								
	Clone 1	Clone 2	Clone 3	Clone 4	Clone 5	Clone 6	Clone 7	Clone 8	Average
Hagerstown	5.7	5.3	5.2	4.3	2.4	2.8	2.0	1.8	3.7
Dekalb	4.7	4.1	3.8	4.0	1.9	2.0	1.4	1.3	2.9
Charlton	4.1	3.1	3.2	3.2	2.6	2.1	1.4	1.6	2.7
Webster	3.7	3.3	3.0	3.1	1.6	1.3	0.9	1.0	2.2
Cecil	2.6	2.2	1.8	1.8	1.5	1.5	0.8	0.7	1.6
Average	4.2	3.6	3.4	3.3	2.0	1.9	1.3	1.3	2.6

The analysis of variance for all clones and all soils indicates a highly significant interaction between soils and clones. It appears, however, that most of the variation contributing to this interaction

can be attributed to the large differences in yields due to clones and soils. A statistical analysis of the yields of the four low-yielding clones (Table 3) shows that the variance due to the interaction of clones and soils is very little greater than that for error. Similarly, the analysis of the four high-yielding clones on the four best soils shows no significant interaction between soils and clones.

TABLE 3.—*Analysis of variance of the yields of various clones of white clover when grown on different soils.*

Source of variation	Degrees of freedom	Mean square	Analysis for the four low-yielding clones		Analysis for the four high-yielding clones*	
			Degrees of freedom	Mean square	Degrees of freedom	Mean square
Soils..........	4	14.481†	4	2.827†	3	8.773†
Replications...	2	0.254	2	0.039	2	0.272
Error (a)......	8	0.608	8	0.237	6	0.613
Clones........	7	18.725†	3	2.233†	3	1.788†
Clones × soils.	28	0.619†	12	0.108	9	0.187
Error (b)......	70	0.112	30	0.092	24	0.098

*The Cecil soil was not included in this analysis because the yields were much lower than on the other soils.
†Highly significant (odds are greater than 99:1).

CALCIUM

The percentage calcium content of the eight clones when grown on each of the five soils is summarized in Table 4. The analysis of variance showed that the differences in calcium content, due both to clones and to soils, were highly significant. (For clones, F=108.9; 1.0% point=2.9. For soils, F=160.4; 1.0% point=7.0). The interaction between clones and soils also appeared to be statistically significant (F=2.1; 1.0% point=2.0). It seems, however, that part of the variation contributing to this interaction is due to the greater range in percentage calcium content of the various clones when grown on Webster, Dekalb, and Cecil soils than when grown on Hagerstown

TABLE 4.—*The calcium content of various clones of white clover when grown on different soils.*

Soil	Calcium content of oven-dry matter, %								
	Clone 3	Clone 1	Clone 7	Clone 2	Clone 5	Clone 4	Clone 6	Clone 8	Average
Webster.....	2.97	2.66	2.41	2.34	2.25	2.19	1.99	1.99	2.35
Dekalb......	2.68	2.54	2.34	2.18	2.08	2.04	1.91	1.71	2.19
Charlton.....	2.40	2.19	1.94	1.88	1.79	1.79	1.69	1.67	1.92
Hagerstown..	2.37	2.22	2.05	1.75	1.73	1.71	1.67	1.63	1.89
Cecil........	2.41	2.09	1.81	1.77	1.87	1.63	1.71	1.40	1.84
Average.....	2.57	2.34	2.11	1.98	1.94	1.87	1.79	1.68	2.04

and Charlton. An examination of the data in Table 4 shows that when the eight clones are arranged according to their percentage calcium content, the rank, except for an occasional tie, is identical whether the clones were grown on Webster, Dekalb, Charlton, or Hagerstown soil. On the Cecil soil the rank is different because the relative calcium content of clones 5 and 6 was slightly higher than when grown on the other soils. Since, however, the discrepancy is small, it is concluded that despite the statistical significance of the interaction between clones and soils, any tendency for a clone to be relatively higher in percentage calcium on one soil than on another is negligible in comparison with the magnitude of the difference among clones.

Differences in the total uptake of calcium by different clones were greater than the differences in either percentage calcium or yields of dry matter. In clone 1, the total calcium content of the harvested material ranged from 54 mg per pot on the Cecil soil to 127 mg per pot on the Hagerstown soil, with an average of 98 mg. In clone 8, the range was from 10 to 29 mg, with an average of 22.

No significance should be attached to the relationship between yields and percentage calcium. These clones were selected to represent a wide range with respect to calcium and phosphorus content rather than to represent the species as a whole. Moreover, preliminary trials with a larger number of clones showed no relationship between yields of dry matter and percentage calcium.

PHOSPHORUS

The percentage phosphorus content of the various clones is summarized in Table 5. As in percentage calcium, differences due to both clones and soils were highly significant. The interaction between clones and soils also appeared to be statistically significant (odds were about 99:1), indicating that some clones were relatively higher in phosphorus on one soil than on another. The values that appear to be significantly out of line are those for clones 5, 6, and, to a lesser extent, 8 on Charlton soil. For each of these three clones the phosphorus content when grown on Charlton soil was lower than the phosphorus content based on the average for all five soils. This was not true for any of the other clones. One other value that appears to be

TABLE 5.—*The phosphorus content of various clones of white clover when grown on different soils.*

Soil	Phosphorus content of oven-dry matter, %								
	Clone 8	Clone 7	Clone 5	Clone 6	Clone 4	Clone 2	Clone 3	Clone 1	Average
Dekalb	0.426	0.362	0.371	0.354	0.303	0.311	0.312	0.239	0.335
Hagerstown	0.409	0.354	0.361	0.341	0.320	0.316	0.289	0.262	0.332
Charlton	0.380	0.348	0.297	0.302	0.291	0.279	0.264	0.260	0.303
Webster	0.392	0.330	0.315	0.321	0.259	0.248	0.237	0.225	0.291
Cecil	0.392	0.317	0.274	0.279	0.240	0.219	0.216	0.194	0.266
Average	0.400	0.342	0.324	0.319	0.283	0.275	0.264	0.236	0.305

out of line is for clone 1 on Dekalb soil. These differences, although statistically significant, are small compared with the differences among clones.

The relationship between the yields of dry matter and the percentage phosphorus content of the eight clones used in this experiment is quite striking. The four high-yielding clones were the lowest in percentage phosphorus content, the two low-yielding clones were highest in percentage phorphorus content, and the two clones that were intermediate in yields of dry matter were intermediate in percentage phosphorus. Although these clones can not be considered as representative of the species, this relationship appears significant in view of the fact that a similar relationship was found in a preliminary trial with a larger number of clones. Thus, under greenhouse conditions, it appears that clones that produce high yields of dry matter are very likely to be low in percentage phosphorus content.

The extremes in yields of dry matter, however, were relatively greater than the extremes in percentage phosphorus so that the total uptake of phosphorus was highest in the clones that were lowest in percentage phosphorus. The total phosphorus content of clones 1, 2, 3, and 4 was about twice as high as that of clones 7 and 8.

POTASSIUM

The data for the potassium content of the different clones on the five soils are summarized in Table 6. Each of the eight clones was highest in percentage potassium when grown on Hagerstown soil and lowest when grown on Webster soil. Differences in potassium content due to clones were also highly significant, although the magnitude of the differences due to clones was not as great as that due to soils. In general, the clones that were high in percentage potassium on one soil were high in percentage potassium on other soils. On Hagerstown soil, however, clone 2 ranked first in percentage potassium content, whereas on the other soils it was only intermediate. Similarly, clone 4 was relatively high in potassium when grown on Cecil soil but was low in potassium on Webster soil. The analysis of variance indicated that these differences were statistically

TABLE 6.—*The potassium content of various clones of white clover when grown on different soils.*

Soil	Potassium content of oven-dry matter, %								
	Clone 8	Clone 7	Clone 2	Clone 4	Clone 3	Clone 6	Clone 5	Clone 1	Average
Hagerstown..	3.77	3.61	3.99	3.50	3.39	3.31	3.34	2.98	3.49
Dekalb......	3.62	3.34	3.00	3.06	2.96	3.00	3.03	2.53	3.07
Cecil........	3.33	3.28	2.89	3.17	2.88	2.72	2.89	2.45	2.95
Charlton.....	3.14	3.46	2.68	2.71	2.79	2.57	2.46	2.44	2.78
Webster.....	2.20	1.87	1.46	1.27	1.46	1.68	1.43	1.16	1.57
Average.....	3.21	3.11	2.80	2.74	2.70	2.66	2.63	2.31	2.77

significant. The F value for the interaction of clones and soils was 3.8 as compared with 2.0 for the 1% point.

DISCUSSION

The data presented in this paper show that under similar environmental conditions a clone that is high in calcium on one soil is very likely to be high in calcium on other soils. To a lesser extent, this would also appear to be true for phosphorus and potassium.

On the other hand, unpublished data obtained in continued studies indicate that under different environmental conditions relative differences in mineral content may not be maintained. Since, however, different plants are known to respond differently with respect to growth habit to variations in day length, light intensity, light quality, temperature, and other environmental conditions, it is not surprising that relative differences in mineral content would also occur. Field observations of the growth habit of the clones used in this investigation showed striking differences during different periods of the season, particularly in regard to degree of flowering and to the duration of the flowering period. Differences were also apparent in other respects. One clone made relatively better growth during midsummer than during the spring or fall. Another clone produced very short petioles and was nearly prostrate in the field, but in the greenhouse the growth habit was similar to that of other clones.

No significance is attached to the inverse relation between the calcium and the phosphorus content of the eight clones used in this investigation because these clones were selected to represent wide differences in calcium and phosphorus and in calcium-phosphorus ratios.

The results do show, however, that calcium and phosphorus may be present in very different ratios in different clones. In clone 8, for example, the calcium-phosphorus ratio averaged 4.2 as compared with 9.9 in clone 1. This difference in calcium-phosphorus ratio might suggest that some clones are better adapted to growth on unlimed soils or on soils low in available phosphate than are other clones. The results obtained with these eight clones, however, show no evidence of such a relationship. Moreover, other trials with these same clones grown on Dekalb soil at two levels of lime and two levels of phosphate failed to show any appreciable relationship between the calcium and phosphorus contents of the plant and the yield response to lime and phosphate.

SUMMARY

Eight clones of white clover were increased vegetatively and grown in the greenhouse on five widely different soils. Yields of dry matter and the contents of calcium, phosphorus, and potassium were determined. Marked differences were obtained in both yields of dry matter and in the mineral content of the different clones.

Clones that were relatively high in calcium on one soil were also relatively high in calcium on other soils.

Relative differences in phosphorus and in potassium content tended to be maintained on different soils, but the agreement was not as close as in the case of calcium.

No relation was found between the mineral content of the clones and their ability to grow at low levels of lime and phosphate.

LITERATURE CITED

1. Brown, D. S., Robinson, R. R., and Browning, G. M. Determination of small amounts of potassium. Ind. & Eng. Chem., Anal. Ed., 10:652–654. 1938.
2. Fiske, C. H., and Subbarow, Y. The colorimetric determination of phosphorus. Jour. Biol. Chem., 66:375–400. 1925.
3. Fort, C. A., and McKaig, Nelson, Jr. Comparative chemical composition of juices of different varieties of Louisiana sugar cane. U. S. D. A. Tech. Bul. 688. 1939.
4. Kramer, B., and Tisdall, F. F. A simple technique for the determination of calcium and magnesium in small amounts of serum. Jour. Biol. Chem., 47: 475–481. 1921.
5. Truog, Emil. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.
6. Woodford, E. K., and McCalla, A. G. The absorption of nutrients by two varieties of wheat grown on the black and gray soils of Alberta. Can. Jour. Res., C, 14:245–266. 1936.

EVALUATION OF SOME MORPHOLOGICAL CHARACTERS OF CORN IN RESPECT TO THEIR USE IN FORECASTING YIELD[1]

KENNETH R. KELLER[2]

THE crop estimator is confronted with the problem of predicting and estimating accurately the yields of major cereal crops such as corn. Information which might lead to the establishment of more accurate and timely estimates of yield would be of value. Consequently, the Corn-Yield-Weather Research Project, a cooperative study between the U. S. Dept. of Agriculture and the Iowa Agricultural Experiment Station, was initiated in 1938. This project had as one of its objectives an investigation of the possibility of relating certain morphological characters measured at various stages in the development of the corn plant with its ultimate yield, and certain phases of this investigation are reported here.

REVIEW OF LITERATURE

Most of the previous work has stressed the relation of ear characters and other plant measurements with the yield of the progeny from these plants. Much of this work was carried on to learn the association between the standards advanced by the various score cards for show ears and the ability of those ears meeting the requirements to produce high yields. The earlier investigators almost without exception have reported that the correlations were small and were not of much value as an index of selection (3, 4, 5).[3]

Kiesselbach (8) and Richey (9) found that the tendency of certain strains to produce high-yielding crosses was very noticeable. In some later work Richey and Mayer (10) found that some inbred lines were much superior to others in producing high-yielding crossbred combinations. Correlation coefficients between the yielding ability and other characters of inbred variety crosses have been reported (6).

Jenkins (7) reported coefficients of correlation (a) among characters within the same generation of inbred lines, (b) between characters of the inbred parent lines and the same character in the crossbred progeny and, (c) between characters of the inbred parent lines and the yield of the crossbred progeny.

Shafer and Wiggans (12) attacked the problem of relating the characteristics of corn plants to the yield of similar plants. Working with single crosses, double crosses, and top crosses, they reported correlation coefficients of .60 to .85 between weight of total dry matter produced and the weight of the dry shelled grain. Studies of this nature are rather limited. It is this type of relationship which is of interest in this investigation.

---

[1]Joint contribution from the Farm Crops Subsection and the Statistical Section, Iowa Agricultural Experiment Station, Ames, Iowa, cooperating with the Division of Cereal Crops and Diseases, Bureau of Plant Industry and the Agricultural Marketing Administration, Bureau of Agricultural Economics, U. S. Dept. of Agriculture. Journal paper J-1008 of the Iowa Agricultural Experiment Station Projects 163 and 610. Received for publication July 3, 1942.

[2]Research Assistant, Farm Crops Subsection, and formerly Research Graduate Assistant, Statistical Section, Iowa Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 953.

EXPERIMENTAL METHODS

During the season of 1940 two double crosses and four single crosses were grown in a randomized complete block design with four replications at each of four experiment stations located across the Corn Belt. These experiments were conducted at Lincoln, Nebr.; Ames, Iowa (six replications); Urbana, Ill.; and Wooster, Ohio. At Ames each plot consisted of 17 sampling units. The sampling unit consisted of four hills in a square (three plants per hill). The project was established with the intention of determining, if possible, if certain weather factors and plant characters might be used in making long-range forecasts of yield. The data obtained may be roughly classified into three groups, *viz.*, (a) plant measurements, (b) soil measurements (11), and weather records (2). The plant measurements only will be considered in this study. The object of this paper is to present the relations of the measurable plant characters among themselves and with yield, as well as some supplementary work conducted during 1941.

The procedure followed was to record certain measurements of morphological structures at weekly intervals from a few weeks after emergence of the plant until the time of maturity or final harvest. The measurements consisted of leaf height, leaf area, ligule height, stalk diameter, ear length, and ear diameter. At Ames dry matter determinations on the ear and stalk were made.

Since this study is confined mostly to plant characters, their measurements are described somewhat in detail. Leaf height was measured in centimeters from the base of the plant to the tip of the uppermost out-stretched leaf. Ligule height was measured similarly from the base of the plant to the ligule of the uppermost leaf. The total leaf area of the plant wsa expressed as the sum of the products of the length by the width (centimeters) at the widest part of the individual leaf on the plant. The diameter of the ear as well as the length (centimeters) was measured with the husks intact at all times except at the final harvest. The length of the ear was recorded only as that part of the cob which contained grain. The large and small diameter of the stalk was measured above the first visible node at the surface of the soil. Estimates of dry matter were made weekly from a 200-gram sub-sample on one sampling unit per plot. When ears developed, they were removed from the plant and ground separately for dry matter determinations.

EXPERIMENTAL RESULTS

The results reported are chiefly those obtained at Ames, Iowa, during 1940. Several of the analyses of variance for that year are presented in Table 1.

The data are for dates in which two units per plot were sampled thus permitting an estimate of the sampling error involved. It will be noted that the sampling errors and the experimental errors are of about the same size. The experimental error, therefore, is largely composed of sampling variation, a result, doubtless, of the small number (two) of sampling units available. Owing to the weekly dry matter determinations, material was not available for more extensive sampling. Another point of interest is the ratio of the standard deviation to the mean dry weight for the two dates shown in Table 1. This coefficient of variability of 21.4% on June 28 as compared to 10% on August 2 emphasizes that for equal accuracy larger samples should be taken at the earlier date. This conclusion is substantiated by the two coefficients of variability for leaf height. The intervening

weather affects the correlation between a plant measurement and final yield, thus adding to the difficulty of making early season forecasts.

TABLE 1.—*Analysis of variance of yield of dry matter and leaf height on June 28 and August 2 and for ligule height on August 2, Ames, Iowa, 1940.*

Source of variation	Degrees of freedom	Yield of dry matter		Leaf height		Ligule height Aug. 2, mean square
		June 28, mean square	Aug. 2, mean square	June 28, mean square	Aug. 2, mean square	
Total	59					
Replications	4	5137.8	55,412.3	280.5	119.4	23.9
Varieties	5	7005.7*	270,708.9*	748.6*	2126.9*	2037.8*
Experimental error	20	1483.0	39,269.5	64.9	81.8	92.8
Sampling error	30	1657.5	36,922.8	46.4	70.7	76.6
Coefficient of variation ($s/\bar{x}$)		21.4	10.0	8.7	3.9	5.3

*Significant at 1% level.

For the purpose of forecasting yield the changes in coefficients of variability as the plant develops would seem to be essential information. Table 2 shows comparable coefficients of variability of various characters measured during a 3-year period. Without exception these coefficients decrease as the season advances, emphasizing the inaccuracy of early season forecasts as compared to those made later.

CORRELATION STUDIES

The data were used to study the inter-relationships between certain measurable morphological plant characters and also the association of these characters before maturity with final yield.

Because measurements of leaf area require considerable time, they were taken only twice during the season. In 1940, leaf area was determined on June 28 and on August 2. At the earlier date one hill (three plants) per variety per replication was selected at random and the leaf area of the individual leaves of each of the three plants was recorded. On August 2, two hills, one hill in each of two sampling units, for each plot and replication were measured. Bair (1) investigated the possibility of estimating total leaf area from the areas of three leaves only by modifying a formula for the area under a parabolic curve. This formula was tested using the 1940 data. The estimated leaf area was expressed as:

$$\frac{A_t + 4A_m + A_b}{6}(N - 1) + \frac{A_t + A_b}{2}$$

where A_t = area of the uppermost leaf; A_b = area of the lowermost leaf; A_m = area of the middle leaf (in the case of an even number of leaves this would be the area of the two center leaves divided by 2); and

TABLE 2.—*Coefficients of variability for several plant measurements made at different stages of development, Ames, Iowa, 1938–40.*

Plant measurements	Coefficient of variability
Dry weight determinations:	
June 28, 1940	8.72
Aug. 2, 1940	4.08
Aug. 1, 1939	4.04
Ligule height:	
July 1, 1939	4.65
Aug. 1, 1939	1.52
Aug. 1, 1938	3.73
Aug. 2, 1940	2.14
Leaf height:	
June 28, 1940	3.57
Aug. 2, 1940	1.60
Leaf area:	
July 1, 1939	4.80
Aug. 1, 1939	1.57
Greater stalk diameter:	
July 1, 1938	3.44
July 1, 1939	2.21
Aug. 1, 1939	2.36
Final yield:	
1938	5.56
1939	3.87
1940	5.71

N = the total number of leaves. The application of this formula to the present data (Table 3) shows that the total leaf area is satisfactorily estimated.

Although leaf area measurements are more difficult to make at an early date, the results indicate that the formula is equally effective in estimating leaf area at the two dates. This method would simplify the field measurements and reduce the clerical work of estimating total leaf area.

The relation of ligule height to leaf height was investigated. The results presented in Table 4 suggest that only one of these measurements is necessary to indicate plant height. Since ligule height is the easier to determine, it would seem desirable to accept this measurement. The low correlation coefficients for Iowa 939 and $WF_9 \times 38$–11 on July 26 and on August 2, respectively, may be explained by wind damage to the upper leaves. The destruction of parts of the upper leaves lessens the value of leaf-height measurements and reduces the correlation coefficient.

TABLE 3.—*Correlation between actual leaf area and estimated leaf area, with correlation coefficient for each variety or cross, Ames, Iowa, 1940.*

Date measured	Iowa 939	U. S. 44	A×90	R_4 ×Hy	WF_9 ×38–11	L317 ×187–2	Reids'	Total all varieties
June 28	0.94	0.97	0.96	0.98	0.96	0.99	0.96	0.97
Aug. 2	0.95	0.98	0.94	0.92	0.98	0.97	0.96	0.97

TABLE 4.—*Correlation of ligule height with leaf height, with correlation coefficient for each variety or cross, Ames, Iowa, 1940.*

Date measured	Iowa 939	U. S. 44	A×90	R_4 ×Hy	WF_9 ×38–11	L317 ×187–2	Reids'	Total, disregarding varieties
June 28....	0.96	0.96	0.98	0.99	0.97	0.97	0.98	0.97
July 5.....	0.96	0.99	0.83	0.95	0.89	0.94	0.92	0.97
July 12....	0.99	0.97	0.96	0.99	0.97	0.69	0.99	0.97
July 19....	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.96
July 26....	0.50	0.99	0.87	0.99	0.99	0.98	0.92	0.82
Aug. 2.....	0.88	0.95	0.81	0.81	0.50	0.81	0.95	0.80

The relation of plant height to total dry weight of the above-ground parts of the plant was investigated. Plant height and dry weight would be expected to increase in about the same proportion from a few weeks after emergence until the time of flowering. Since ligule height measurements were not available when the first two dry matter determinations were made, leaf height was used at these dates. The results of this study are shown in Table 5.

TABLE 5.—*Correlation of plant height with dry weight, Ames, Iowa, 1940, with correlation coefficients for each variety or cross.*

Date measured	Iowa 939	U. S. 44	A×90	R_4 ×Hy	WF_9 ×38–11	L317 ×187–2	Reids'	Total, disregarding varieties
				Leaf Height				
June 14....	0.92	0.96	0.89	0.98	0.98	0.98	0.95	0.96
June 21....	0.95	0.90	0.98	0.95	0.93	0.99	0.88	0.87
				Ligule Height				
June 28....	0.92	0.85	0.95	0.96	0.91	0.97	0.94	0.87
July 5.....	0.88	0.96	0.36	0.95	0.94	0.91	0.88	0.85
July 12....	0.99	0.99	0.91	0.99	0.95	0.95	0.97	0.92
July 19....	0.91	0.96	0.98	0.95	0.93	0.98	0.88	0.90
July 26....	0.83	0.97	0.32	0.99	0.96	0.85	0.76	0.83
Aug. 2.....	0.25	0.75	0.60	0.77	0.31	0.78	0.80	0.42

These correlation coefficients indicate that plant height could replace dry matter determinations at least part of the time two weeks before the plant flowers. Similar associations following flowering have been studied but have failed to yield consistent results. During the 1939 and 1938 seasons the latest dates which exhibited high correlations between plant height and dry weight were on July 7 and July 22, respectively, emphasizing that it is the stage of development of the plant that governs these relationships, not the calendar date.

YIELD PREDICTION STUDY

In attempting to predict corn yields from morphological plant characters it is essential to know which character or combination of characters gives the most information. In the course of the examination of the data, three characters, (a) ligule height, (b) ear size (the product of the length by the diameter), and (c) the number of ears, were found to be associated with yield. Correlation coefficients obtained were .94, .87, and .64, respectively, using the pooled information from all varieties.

Before computing a regression equation for forecasting yield it would seem desirable to determine the period in the development of the plant when measurements, such as ear size, may forecast yield with maximum precision. The data used in our regression studies were taken when the ears were at their maximum size, which was approximately three weeks after the date on which 50% of the plants were silked. In 1940 at Ames, ear measurements were made at weekly intervals on one hill per plot for each of the varieties. Identical ears were measured each week so the change in size could be studied.

If the differences in ear measurements between dates are large in comparison to the sampling error, then in correlating yield with ear size it would be more important to make the measurements when the ears approach a definite stage of development rather than taking a larger sample. The sampling variation of ear measurements (length $\times$diameter) at the time of maximum ear size was estimated using the formula

$$V=(LD^2)\left(\frac{V_1}{L^2}+\frac{V_2}{D^2}+\frac{2r\sqrt{V_1V_2}}{LD}\right)$$

for the variance of a product, where L^2=mean length squared; D^2=mean diameter squared; V_1=variance of the length within a sampling unit; and V_2=variance of the diameter within a sampling unit.

This mean square, $V=680.15$, is an estimate of the average variance of ear size within a sampling unit which is probably the best approximation to the sampling error of ear size that we have. Data from other sources have shown that the variability among ears from hill to hill within a small area is about the same as the variability within a hill; thus 680.15 is considered a suitable estimate of the sampling mean square. This gives 2.56 square cms as the standard error of the average ear size which may be compared with the deviations of the means for ear size measurements taken at an interval of a week before and after the date of maximum ear size. The means of ear size at the three successive dates were 120.9, 122.2, and 117.4 square cms. The deviation in mean ear size between the first measurement and that made at the maximum ear size is less than the standard error. This indicates that the ears should be measured at the time of maximum size so the error resulting from date of measurement is the minimum. Two comments should be made on this point. First, it was found that the ears from a single hill per plot constituted too small a sample for reliable results. Second, evidence from subsequent samplings has indicated

that measurements on the unshucked ear may not be so accurate as those on shucked ears, and that, in some seasons at least, the sizes of shucked and unshucked ears do not reach their maximum at the same date.

Plant height was found to have reached its maximum several weeks before the time of maximum ear size measurements.

Three variates were used in each of two multiple covariance analyses for computing regression equations. Data were available for six varieties at each of four stations for 1940. Ligule height and ear size were used as the independent variables with yield, the dependent variable, in one case, whereas the number of ears×ear size and ligule height constituted the independent variables in the other case. The errors of estimate for the multiple covariance analyses are shown in Table 6.

TABLE 6.—*Analyses of multiple covariance in corn data for six varieties grown at each of four stations, 1940.*

Source of variation	Errors of estimate					
	Ligule height and ear size			Ear size×number of ears and ligule height		
	Degrees of freedom	Mean square	R	Degrees of freedom	Mean square	R
Variety+error.	18	66.52	0.71	18	44.22	0.73
Error.........	13	66.24	0.38	13	40.94	0.40
Variety.......	3	15.52	0.98	3	18.83	0.97

The regression equations which were computed for variety and variety+error in each case appeared promising when applied to other plant measurement data. These regression equations were used in predicting the 1938 and 1939 yields at Ames as well as the 1940 yields at Clarinda, Iowa (Table 7).

It may be noted that no single equation proved consistently the best in the prediction tests. Equation B, in which the number of ears was omitted, gave the greatest accuracy on an average, but it is assumed that under practical conditions number of ears would be an important factor. Failure of equation C, which contained number of ears as a factor, to give a close prediction at Clarinda may be a result of sampling error. A comparison of the actual and predicted yields indicates that in seasons similar to those investigated plant measurements may be useful in forecasting corn yields.

Since the data available for testing the regression equations was rather limited, a study was made to determine their value in predicting yields for plant measurements collected in other years. In 1941, ligule height, ear size, and the number of ears were recorded from the single cross experimental test plots at seven locations in Iowa. The measurements were recorded from all of the plants in a 2×10 hill plot in each of three replications at a location for each cross, when ear size

TABLE 7.—*Actual and predicted yields using the 1940 multiple regression equations.**

	Variety or cross				Mean	Deviation of predicted mean from actual
	Iowa 939	U. S. 44	Black's	Krug		
Ames, Iowa, 1938						
Actual yield......	93.2	96.3	81.4	78.4	87.3	
Predicted yield (A)	87.1	96.6	94.6	89.9	92.0	+4.7
Predicted yield (B)	82.2	88.7	86.1	83.2	85.0	−2.3
Predicted yield (C)	84.3	95.4	90.5	83.4	88.4	+1.1
Predicted yield (D)	80.8	89.1	81.8	78.7	84.8	−2.5
Ames, Iowa, 1939						
Actual yield.......	93.6	96.4	83.3	82.1	88.7	
Predicted yield (A)	89.0	99.2	94.6	88.1	92.7	+4.0
Predicted yield (B)	84.8	91.3	86.9	81.9	86.2	−2.5
Predicted yield (C)	87.3	95.8	86.6	79.7	87.3	−1.4
Predicted yield (D)	84.1	89.5	81.1	75.6	82.6	−6.1

	Variety or cross					Mean	Deviation of predicted mean from actual
	U. S. 13	U. S. 44	Iowa 13	Iowa 3110	Iowa 960		
Clarinda, Iowa, 1940							
Actual yield.......	86.6	78.0	77.8	84.6	86.3	82.7	
Predicted yield (A)	92.4	92.5	86.1	93.6	91.3	91.2	+8.5
Predicted yield (B)	86.1	82.6	80.8	86.5	84.4	84.1	+1.4
Predicted yield (C)	92.3	91.2	85.7	92.2	92.7	90.8	+8.1
Predicted yield (D)	87.1	86.2	81.7	86.5	87.2	85.7	+3.0

*Regression equations A and B involve ligule height and ear size as the independent variables, while equations C and D involve ear size × number of ears and ligule height as the independent variables. The equations are as follows:

A varieties, $E = .3129X_1 + .3322X_2 - 18.1 \quad s_{y.12} = 3.94$
B variety + error, $E = .1951X_1 + .3397X_2 + 8.2 \quad s_{y.12} = 6.75$
C varieties, $E = .0017X_1 + .2025X_2 - 5.4 \quad s_{y.12} = 4.3$
D variety + error, $E = .0016X_1 + .0845X_2 + 18.4 \quad s_{y.12} = 6.2$

was expected to be near its maximum as determined from the date when 50% of the plants were silked. The number of single crosses measured within a location varied from 20 to 27. The experimental fields were located near Ames, Davenport, Cresco, Clarion, Manchester, Storm Lake, and Sheldon, which are in the central and northern districts of Iowa. The predicted yields have been calculated using regression equation A, previously defined, and the results are entered in Table 8.

A comparison of the actual yield with the predicted yield suggests the possibility of making corn yield forecasts based on measurable plant characters. It may be noted that the agreement between the actual and predicted mean yields for the crosses at the seven locations is quite close. It is also of interest for those familiar with the crosses to notice that these lines which tend to be rather tall are, on the average, overestimated in yield, which may be explained by the overemphasis of plant height in the equation.

TABLE 8.—*Predicted 1941 yields using the 1940 multiple regression equation of yield (Y) on ligule height (X_1) and ear size (X_2) for varieties.*

Single cross	Location														Mean	
	Ames		Davenport		Clarion		Cresco		Manchester		Sheldon		Storm Lake			
	A*	P*	A	P	A	P	A	P	A	P	A	P	A	P	A	P
I205 × I233	86.7	72.7	65.7	84.0	69.4	63.2	47.5	49.2	52.0	54.4	58.1	61.4	78.6	68.9	65.4	64.8
I205 × WF9	95.9	74.2	91.7	83.2	80.2	67.1	49.2	54.2	59.7	58.1	67.4	68.9	80.8	72.7	75.0	68.3
L289 × WF9	87.2	91.5	84.7	99.6	113.6	93.5	52.0	60.8	44.4	61.6	81.5	79.0	94.4	86.8	79.7	81.8
I205 × L289	73.5	87.2	86.4	86.9	—	—	65.1	70.9	36.2	51.5	80.3	73.1	84.4	81.5	71.0	75.2
I198 × WF9	106.8	82.9	96.7	82.1	102.1	81.3	—	—	70.0	60.9	—	—	93.5	85.9	93.8	78.6
I198 × L289	111.3	94.3	87.4	66.5	96.7	89.3	—	—	65.6	71.8	—	—	98.3	91.5	91.9	82.7
I233 × Hy	87.9	78.3	95.7	100.5	82.2	71.1	—	—	78.6	63.1	—	—	81.4	79.9	85.2	78.6
M14 × Oh40B	—	—	—	—	78.1	73.2	56.7	65.1	54.7	57.2	68.4	68.7	74.7	78.5	66.5	68.5
WF9 × M14	—	—	—	—	84.6	71.6	59.2	62.6	54.4	57.1	79.3	70.4	84.4	77.6	72.4	67.9
KB397 × WD456	—	—	—	—	79.2	71.2	50.1	62.4	57.9	64.1	73.2	80.5	71.6	78.8	66.4	71.4
KB397 × WF9	—	—	—	—	85.9	68.3	55.6	55.6	46.8	52.0	81.7	72.7	66.5	71.2	67.3	64.0
Fe × Oh40B	—	—	—	—	81.8	76.6	51.8	57.6	49.4	58.0	59.3	66.1	84.5	85.9	65.4	68.8
Fe × M14	—	—	—	—	87.2	76.5	59.1	60.6	47.2	54.2	73.9	74.1	80.3	81.9	69.5	69.5
WD456 × M14	—	—	—	—	95.9	80.4	51.5	60.1	49.1	67.4	77.1	75.0	83.1	86.1	71.3	73.8
I205 × M14	—	—	—	—	89.8	71.1	60.3	61.7	51.1	59.9	75.1	69.3	85.1	75.0	72.3	67.4
I205 × Oh40B	—	—	—	—	88.9	79.0	56.0	59.4	70.8	66.0	83.4	74.8	85.9	82.0	77.0	72.2
I233 × KB397	—	—	—	—	80.1	73.3	49.5	54.8	59.5	66.7	75.1	76.6	83.1	77.4	69.5	69.8
I233 × Fe	—	—	—	—	82.8	80.3	42.1	51.2	34.3	50.5	77.1	72.2	75.8	78.9	62.4	66.6
I233 × M14	—	—	—	—	87.7	74.8	49.5	55.0	41.6	52.7	68.7	69.7	84.5	76.8	66.4	65.8
L289 × WD456	—	—	—	—	86.6	91.7	52.5	78.0	52.6	56.4	80.5	88.5	78.8	90.0	70.2	80.9

L289 × M14	—	—	—	—	92.9	84.0	55.0	65.9	69.1	69.5	77.9	78.4	89.4	89.7	76.9	77.3
L289 × Fe	—	—	—	—	90.0	84.3	50.1	54.0	52.9	60.4	70.8	79.2	90.0	89.2	70.3	73.4
KB397 × M14	—	—	—	—	85.6	73.2	61.2	60.2	65.4	69.1	70.3	73.0	72.4	75.0	71.0	70.1
I205 × 187-2	92.7	88.7	91.7	80.6	93.7	79.4	—	—	—	—	—	—	85.7	80.4	91.0	82.3
Os420 × 187-2	—	—	—	—	90.4	82.3	—	—	35.8	56.9	—	—	71.5	87.2	65.9	75.5
Os420 × Hy	—	—	—	—	86.7	81.6	—	—	74.3	71.8	—	—	92.4	87.0	84.6	80.1
Os420 × WF9	—	—	—	—	81.9	80.8	—	—	39.1	56.1	—	—	84.4	83.0	68.4	73.3
K_4 × M940	111.2	100.8	101.6	76.9	—	—	—	—	—	—	—	—	—	—	106.4	88.8
159L_1 × L317	96.2	96.9	96.9	92.2	—	—	—	—	—	—	—	—	—	—	96.5	94.5
159L_1 × Hy	66.1	94.5	93.1	96.2	—	—	—	—	—	—	—	—	—	—	79.6	95.3
I198 × M940	112.5	88.2	96.8	84.5	—	—	—	—	—	—	—	—	—	—	104.6	86.4
I198 × K_4	112.1	93.0	82.7	84.9	—	—	—	—	—	—	—	—	—	—	97.4	89.0
I198 × L317	113.7	99.8	96.9	97.6	—	—	—	—	—	—	—	—	—	—	105.3	98.7
I224 × L317	105.6	101.2	100.2	82.4	—	—	—	—	—	—	—	—	—	—	102.9	91.8
I224 × WF9	85.5	84.0	89.8	82.3	—	—	—	—	—	—	—	—	—	—	87.6	83.2
I224 × 38–11	90.9	84.8	79.3	85.0	—	—	—	—	—	—	—	—	—	—	85.1	84.9
I224 × K_4	102.5	93.9	89.4	92.1	—	—	—	—	—	—	—	—	—	—	96.0	93.0
I233 × 187-2	79.9	77.5	84.4	87.8	—	—	—	—	—	—	—	—	—	—	82.1	82.6
187–2 × WF9	86.4	92.7	91.3	95.6	—	—	—	—	—	—	—	—	—	—	88.8	94.2
I233 × ITE701	92.0	81.8	—	—	—	—	—	—	—	—	—	—	—	—	92.0	81.8
Mean	95.0	88.5	90.1	87.0	87.5	77.6	53.7	59.9	54.3	60.2	74.0	73.6	82.8	81.4	80.3	78.3

$$E = .3129X_1 + .3322X_2 - 18.1 \qquad s_{y\cdot 12} = 3.94$$

*A = Actual yield; P = Predicted yield.

The relation between ligule height and yield and between ear size and yield was investigated in 1941 plant measurement data. The correlation coefficients obtained, using the pooled information from all varieties, were .44 and .78, respectively, as compared to .94 and .87 for the previous year.

TABLE 9.—*Constants of multiple regression of yield on ligule height and ear size in 24 single crosses grown at seven locations in Iowa, 1941.*

Variety	Partial regression		Correlation coefficient
	Yield on ligule height	Yield on ear size	
I198×WF9	0.053	0.995	0.78
I198×L289	0.721	0.726	0.98
I233×Hy	0.246	0.342	0.56
M14×Oh40B	−0.078	0.576	0.74
WF9×M14	2.342	0.266	0.69
KB397×WD456	−0.397	1.463	0.59
KB397×WF9	−1.074	1.391	0.88
Fe×Oh40B	−0.145	0.572	0.77
Fe×M14	−0.308	1.053	0.93
WD456×M14	−0.268	0.925	0.97
I205×M14	−0.320	1.493	0.94
I205×Oh40B	0.425	0.650	0.70
I233×KB397	0.431	0.946	0.48
I233×Fe	0.684	0.702	0.90
I233×M14	0.304	1.254	0.99
I289×WD456	1.294	1.532	0.89
L289×M14	−0.444	1.428	0.93
L289×Fe	−0.415	1.217	0.98
KB397×M14	0.088	1.028	0.75
I205×I233	0.667	0.938	0.88
I205×WF9	−0.370	2.418	0.88
I205×L289	−1.557	0.858	0.98
I205×187-2	−0.232	0.366	0.61
L289×WF9	0.118	1.246	0.93

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares
Deviations from average regression within varieties	102	8595.81	
Deviation from individual variety regressions	24	5837.71	243.24
Differences among variety regression coefficients	78	2758.10	35.36

The varieties in 1941 were purposely selected to have a wide range of height. This would cause a greater variability in the levels of the individual variety regressions, or a greater amount of scatter about the average regression which was used.

Regression equations were computed on the 1941 data using (a) ligule height and (b) ear size as the independent variables with yield, the dependent variable. All of the crosses at each location were included. However, in calculating the partial regression coefficients only those crosses that appeared in at least four of the locations were used. The results of this study and the analysis of variance are presented in Table 9.

Although the values of each set of coefficients vary considerably among the varieties it may be noted in the analysis of variance that the mean square for differences among coefficients of the variety regressions of 35.36 when compared with the mean square for deviations from individual variety regressions of 243.24 is actually less than error indicating that the average regression may be regarded as the best available estimate of the population regression.

The regression equation computed from the variety sum of squares gave the best results when attempting to predict the 1940 yields. This equation and the actual and predicted yields are presented in Table 10 as well as the results of a similar equation using ligule height and ear size × number of ears as the independent variables.

The agreement between the actual and predicted yields in both cases is close. The equation based on ligule height and ear size as its independent variables has predicted the yields better than the other equation which involves ligule height and number of ears × ear size. More data are necessary, however, for an adequate test.

The latter equation, which involves ligule height and ear size × number of ears, when based on the 1940 data, failed to predict the 1941 yields very accurately. Since the number of ears was fairly constant in 1940 as compared to 1941, it may in part account for the failure of the 1940 regression to predict the 1941 yields as well as the 1941 regression predicted the 1940 yields.

SUMMARY

The inter-relationships between certain measurable morphological plant characters and also the relationship of these characters before maturity with final yield in bushels per acre were investigated.

From a study of the inter-relationships of morphological characters at Ames, Iowa, in 1940, the following were shown to be highly correlated: Leaf height and ligule height; plant height increase and dry weight increase up to flowering; and actual leaf area and estimated leaf area.

It was suggested that the distance from the soil surface to the ligule of the upper leaf was a sufficiently accurate measure of plant height. Using the formula developed for the purpose, leaf area measurement made on the upper, lower, and center leaves of the plant could possibly render measurement of the remaining leaves unnecessary.

Among the characters used in predicting yield, plant height remained constant for a period shortly after flowering to maturity and ear size measurements, at time of maximum size, remained near the same magnitude for at least a week. The number of ears could be determined at the time the ears had reached their maximum size.

TABLE 10.—*Actual and predicted yields using the 1941 regression equations in predicting the 1940 yields.**

Variety	Location												Mean		
	Ames			Lincoln			Urbana			Wooster					
	A	P†	P‡	A	P†	P‡	A	P†	P‡	A	P†	P‡	A	P†	P‡
Iowa 939	93.2	74.3	80.0	38.6	24.3	36.7	66.5	76.1	83.6	118.9	122.7	116.4	79.3	74.4	79.8
U. S. 44	89.5	91.8	93.7	44.1	46.2	54.4	83.6	73.2	83.0	127.7	144.1	136.7	86.2	88.8	91.9
A × 90	69.8	65.3	72.9	45.4	32.2	48.0	65.7	63.3	72.8	102.7	98.1	99.2	70.9	64.7	73.2
R_4 × Hy	78.0	80.2	79.8	41.3	53.9	63.8	77.0	74.3	83.0	117.0	115.6	111.6	78.3	81.0	84.5
WF_9 × 38–11	91.0	83.9	85.5	49.8	53.1	60.4	72.7	69.2	79.6	124.7	134.9	123.9	84.5	85.0	87.3
L317 × 187–2	87.1	98.2	100.0	47.9	56.8	67.3	93.1	80.9	90.5	134.3	143.9	134.8	90.6	95.0	98.1
Mean	84.7	82.3	85.3	44.5	44.4	55.1	76.4	72.8	82.1	120.9	126.4	120.4	81.6	81.5	85.8

*A = Actual yield; P = Predicted yield.

†P = ("a" ligule height and "b" ear size) $E = .5053X_1 + .5274X_2 - 78.3$ $s_{y.12} = 7.52$

‡P = ("a" ligule height and "b" ear size × no. of ears) $E = .3156X_1 + .0084X_2 - 31.4$ $s_{y.12} = 14.3$

Regression equations based on the 1940 data from Ames, Iowa; Lincoln, Nebr.; Urbana, Ill.; and Wooster, Ohio, were tested on data obtained in the following trials to determine the agreement between the actual and predicted yields: The 1938 and 1939 yields at Ames, the 1940 yields at Clarinda, and the 1941 yields from seven single cross tests in central and northern Iowa (Tables 7 and 8).

Regression equations computed from the experimental tests of single crosses in 1941 were used in the prediction of the 1940 yields at the four experiment stations (Table 10).

The general approach of using regression equations computed from various plant measurements appears to offer some promise as a method of forecasting yields of corn.

LITERATURE CITED

1. BAIR, R. A. Influence of weather on growth and yield of maize. Unpublished Ph.D. Thesis, Library, Iowa State College, Ames, Iowa. 1940.
2. ———. Climatological measurements for use in the prediction of maize yield. Ecology, 23:79–88. 1942.
3. BRIGHAM, A. A. Der mais. Ein Beitrag zur Geschichte der Entwicklung seines Anbaues und Schilderung einer Reihe systematischer Untersuchungen zum Zwecke der Verbesserung seiner zucht und der Steigeuing seiner Ertrage. Gottingen Dissertation. 1896.
4. ETHERIDGE, W. C. Characters connected with the yield of the corn plant. Mo. Agr. Exp. Sta. Bul. 46. 1921.
5. EWING, E. C. Correlation of characters in corn. Cornell Univ. Agr. Exp. Sta. Bul. 287. 1910.
6. HAYES, H. K., and JOHNSON, I. J. The breeding of improved selfed lines of corn. Jour. Amer. Soc. Agron., 31:710–724. 1939.
7. JENKINS, M. T. Correlation studies with inbred and crossbred strains of maize. Jour. Agr. Res., 39:677–721. 1929.
8. KIESSELBACH, T. A. Corn investigations. Nebr. Agr. Exp. Sta. Res. Bul. 20. 1922.
9. RICHEY, F. D. Effects of selection on the yield of a cross between varieties of corn. U. S. D. A. Bul. 1209. 1924.
10. ———, and MAYER, L. S. The productiveness of successive generations of self-fertilized lines of corn and of crosses between them. U. S. D. A. Bul. 1354. 1925.
11. RUSSELL, M. B., DAVIS, F. E., and BAIR, R. A. The use of tensiometers for following soil moisture conditions under corn. Jour. Amer. Soc. Agron., 32:922–930. 1940.
12. SHAFER, JOHN JR., and WIGGANS, R. G. Correlation of total dry matter with grain yield in maize. Jour. Amer. Soc. Agron., 33:927–932. 1941.

NOTES

FACTORS AFFECTING THE DETERMINATION OF pH OF SOME MEDITERRANEAN SOILS

IN a previous article, the author[1] dealt with the question of how KCl/N is influencing the pH of soils. The present investigation shows that by adding KCl/N as a soil solvent, hydrolysis is prevented, and any soil-solvent ratio can be used without any change occurring in the pH.

The soil samples used for this experiment represent four profiles, two light soils (one with and one without $CaCO_3$) and two heavy soils (one with and one without $CaCO_3$). The soil samples were taken at the arbitrary depths of 0 to 25 cm, 25 to 50 cm, 50 to 75 cm, and 75 to 100 cm.

The pH values of these soils have been determined, using air-dried soil extracted in varying soil-solvent ratios and with different solvents and shaking them for 3 minutes according to the method adopted by Gedroiz.[2] The pH was determined in colorimetric measurements as described by the author.

In order to confirm results obtained in our laboratory, the pH was determined electrometrically on parts of the same soil samples by the Chemico-Physical Department of the Hebrew University. The results obtained were similar to ours.

It will be observed from Fig. 1 that by using distilled water as a medium the pH increases with dilution. This increase may be attributed to the fact, as expressed by McGeorge,[3] that by increasing dilution the potential alkaline reaches a higher hydrolysis. On the other hand, by using tap water or KCl/N as a solvent very little change in the pH occurs. This is probably due to the buffer action of KCl/N

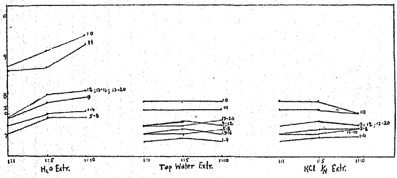


FIG. 1.—Results of pH determinations using different solvents.

[1]PUFFELES, M. The influence of exchangeable-ions and neutral salts on the pH of soils. Jour. Amer. Soc. Agron., 31: 762–766. 1939.

[2]GEDROIZ, K. K. Lehrbuch der Bodenanalyse. Verlag Gebr. Bodentraeger: 147–177. 1932.

[3]McGEORGE, W. T. Factors contributing to the reaction of soils and their pH measurements. Ariz. Agr. Exp. Sta. Tech. Bul. 78. 1938.

and to the influence on the reaction of the soils of CO_2 gas, CO_2 dissolved, CO_3 ion, and HCO_3 ion. It is suggested, however, that since tap water varies greatly and since it is exposed to the air so that its pH is increasing owing to changes upon equilibria between CO_2 HCO_3 ion, and CO_3, KCl/N might be used as a soil solvent.—M. PUFFELES, *Government Central Laboratories, Department of Health, Jerusalem, Palestine.*

A FERTILIZER TRIANGLE FOR SMALL WHOLE NUMBER FERTILIZER RATIOS

THE limitation of fertilizer grades on some basis of fixed ratios of nitrogen to phosphate to potash has long been approved in principle. The tendency in this direction has received recently an additional impetus through an action taken as a war measure in the Middle Atlantic states. Similar action elsewhere is anticipated. The action provides for the tentative limiting of fertilizers to certain grades that follow a small whole number ratio system.

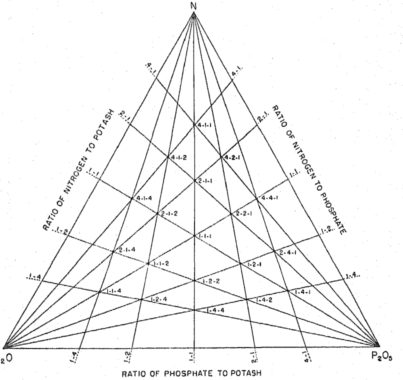


FIG. 1.—A fertilizer triangle to show the location of small whole number ratios at each intersection of three ratio lines.

It is probable that the effects of the action will continue to influence fertilizer sales and recommendations long after the "duration" and the time seems opportune, therefore, to present a diagramatic representation of small whole number ratios in their relation to all possible fertilizer combinations. All that is required is a modification of the equilateral triangle that is commonly used to illustrate ratio relationships.

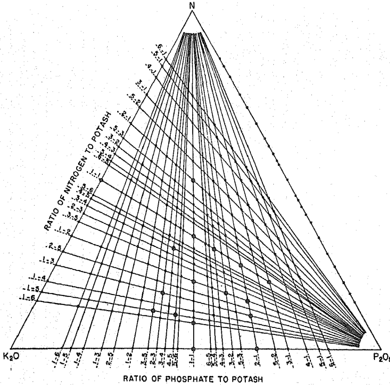


FIG. 2.—A fertilizer triangle to show the distribution of all small whole number ratios that can be expressed in numbers not greater than six.

Proof can be given to show that if each apex point of the triangle represents a 100% proportion of one of the three variables that are included in a complete fertilizer ratio, and the base line opposite represents a zero percentage of that variable, then a line drawn from any apex to any point on the opposite base becomes the locus of all points that represent the same fixed ratio of the two other variables. The ratio of the two variables is determined by the proportions into which the base is divided by its intersection with the line from the apex.

These conditions are illustrated in the triangle of Fig. 1. Radial lines have been drawn from the apexes to designate ratios of 4–1,

2–1, 1–1, 1–2, and 1–4 of nitrogen to potash, nitrogen to phosphate, and phosphate to potash. Small whole number ratios occur wherever three radial lines intersect and give a basis for series of fertilizers that are variable with respect to only one constituent. Such a system of fertilizers should have advantages in making fertilizer recommendations and in devising fertilizer experiments.

In Fig. 2, the lines of all small whole number ratios for two constituents are shown from 6–1 to 1–6. However, the nitrogen-phosphate ratio lines that have these numerical values have been omitted to reduce crowding of the diagram. The omission is not serious since the intersection of two lines is sufficient to fix a point, and the complete fertilizer ratio that occurs at any point of intersection may be determined by inspection. As an example, the intersection of the 2–3 line that represents the ratio of nitrogen to potash with the 4–3 line that represents the ratio of phosphate to potash indicates the position on the triangle of the 2–4–3 fertilizer ratio.

It should be evident from Fig. 2 and the explanation that has been given that the use of the modified triangle is not restricted to small whole number ratios. Any fertilizer may be located on the triangle by the intersection of its nitrogen to potash and phosphate to potash ratio lines.

The dotted intersections of Fig. 2 show the distribution of all fertilizer ratios that can be expressed in whole numbers not greater than 6. A total of 181 complete fertilizer ratios are represented, but many of these have but little commercial or agricultural significance, and the number of ratios that represent the better balanced fertilizers appears to be greater than necessary to meet all ordinary fertilizer needs. A comparison of Figs. 1 and 2 suggests the possibility of developing an easily comprehended system of fertilizer ratios by the selection or elimination of groups of ratios that correspond to fixed ratio lines.

The circles shown on Fig. 2 designate the fertilizer ratios that were tentatively selected for the Middle Atlantic states.—C. S. SLATER, *Soil Conservation Service, Maryland Agricultural Experiment Station, College Park, Md.*

BOOK REVIEWS

SAMPLING METHODS IN FORESTRY AND RANGE MANAGEMENT

By F. X. Schumacher and R. A. Chapman. Durham, N. C.: Duke Univ. School of Forestry. Bulletin 7. 213 pages, illus. 1942. Paper, $2; cloth, $2.50.

APPEARANCE of this bulletin on sampling methods in forestry and range management will be welcomed by those vested with the responsibility of sampling timber or range and pasture lands.

Sampling of timber and range lands is difficult because of the typically irregular conformation and often unknown area of timber and range plant types. Plant societies are complex and it is necessary to sample from two to many populations simultaneously. The

authors, cognizant of the requirements for efficient sampling systems on timber and range lands have assembled many systems that are more directly applicable to the problems being confronted than was heretofore available. Some of the methods discussed which should find favor are (1) stratified or representative sampling; (2) simultaneous sampling of two or more populations; (3) representative sampling of diverse, but unknown, areas; and (4) regression in representative sampling.

The range ecologist will be disappointed in the actual content of the bulletin, especially in view of the promise held by the title. The bulletin is replete with examples of sampling drawn from timber land management but is devoid of any examples drawn from range or pasture forage inventories or from range research. Nor is more than passing mention given to any of the specific problems of sampling ranges or pastures, the assumption being made that the problem is identical to that of sampling in timber lands.

The dissimilarity of forest surveys and range or pasture forage inventories in type of characteristic being observed, character of sampling unit that it is possible to use, and ability to check ocular estimates still leaves personal ingenuity free play in adapting sampling systems suggested by the authors to specific sets of conditions.

Many readers may find the authors' discussions of the different sampling systems and the reduction of the data to statistics rather difficult to master because of their distinctly mathematical flavor. This is not serious, but it will deter from more widespread use of some systems advocated.

We have pointed out what appears to be the major shortcomings from the standpoint of range or pasture inventories. To the forester interested primarily in timberland management and to the mathematically inclined, this bulletin should be especially welcome. (J. F. P.)

FIELD CROPS AND LAND USE

By Joseph F. Cox and Lyman Jackson. New York: John Wiley & Sons, Inc. XIV+473 pages, illus. 1942. $3.75.

IN a foreword to this volume, Claude R. Wickard expresses appreciation that such a book on field crops and land use should appear at the present time, when agriculture has been called upon to furnish foods and raw materials for our nation, our allies, and for the starving millions of Europe after the war, and also when it is so important to increase yields per acre and at the same time conserve and improve soil fertility.

The authors, who are respectively Extension Agronomist, U. S. Dept. of Agriculture and President of South Dakota State College, state that the purpose of the volume, which is designed for the undergraduate college course, is to outline the progress to date in the national program of efficient farming, agricultural adjustment, and conservation. The material drawn upon is the work of the agricultural colleges and experiment stations and the U. S. Dept. of Agriculture. In particular, stress is laid upon the many opportunities

now open to farmers to improve their methods through cooperation with such agencies as extension services, soil conservation, marketing, and the many new agencies of our government aimed at improving farming conditions.

The 16 chapters of Part I deal with such subjects as American agriculture in general; field crops from the standpoints of classification, management, and adaptations; soil fertility and conservation; cover crops and green manuring, pastures, and meadows; weeds; crop pests; and seed growing. Two chapters deal with the home food supply and wildlife maintenance.

Part II (15 chapters) discusses individual field crops from the standpoints of climatic factors, soil requirements, rotation, fertilization, methods of growing, seed production, harvesting, storage, pests, varieties, and food values. The crops covered include all the common ones as grown in both northern and southern United States. The text is followed by a bibliography of 192 titles, an appendix of 24 pages which has tables of percentage composition, food value of crops, and varietal recommendations by states, and a 12-page index.

The volume should be valuable not only to workers dealing with field crops, but also to soil and soil conservation workers and to farmers who are interested in up-to-date methods of agricultural production at this most critical period of our national life. (R. C. C.)

WEED CONTROL

By Wilfred W. Robbins, Alden S. Crafts, and Richard N. Raynor. New York: McGraw-Hill Book Co., Inc. XI+543 pages, illus. 1942. $5.

THE authors, all members of the Botanical Division, College of Agriculture, University of California, at Davis, have produced the most complete work on weed control that the reviewer is aware of. It is written primarily from the California angle, although work done in other states and countries is freely drawn upon. Much of the material is the result of research in California and by the authors themselves.

As the authors clearly point out, most publications on weeds stress description and identification with only minor discussion on control. The increasing importance of weed control, due to the large toll they exact in productive capacity of soils and human effort, makes such a volume especially timely. The surprising thing about the book is the fact that so much material on the subject has been available but was never brought together before.

A critical analysis is made of all methods of control and these are evaluated in terms of practical use and limitations under various conditions. Twenty-four chapters take up such subjects as weeds and human affairs, reproduction, association with soils and crops, methods of prevention of weed spread, principles of control through tillage, biological, chemical, selective action, and soil sterilization methods. One hundred pages are devoted to the various chemicals used in weed control. Other subjects are machinery for applying herbicides, special problems of grasslands, cropped and uncropped areas, and a separate

discussion of each of 21 special weeds which are problems in California.

A 14-page appendix gives data on number of seeds per pound of over 100 different weeds and agricultural crops, reference tables of weights and measures, and many tables on methods of making up herbicides. A great many references are given at the chapter ends and the book has a good author and subject index.

No one working with or interested in weed control can afford to be without this up-to-the-minute manual of a subject whose importance is not sufficiently recognized. (R. C. C.)

THIS LAND WE DEFEND

By Hugh Hammond Bennett and William Clayton Pryor. New York: Longmans, Green & Co. XII+107 pages, illus. 1942. $1.50.

NO matter how well informed one may be on the technical aspects of erosion and soil conservation in America, one will find within the pages of this little book, with its excellent illustrations, a vivid and challenging account of a great national tragedy coupled with a recital of what has been done and must yet be done if America is to go "all out" for the conservation of our foremost natural resource—the soil.

The story is told with all the color and imagination that characterize the writings of the senior author who as a prophet is, fortunately, not without honor in the land. America has taken heed in time—we hope. At least this excellent popular summary of the forces responsible for the deplorable state in which we find such vast areas of our land, concludes with a note of optimism that we have found the means of combating these forces, if we will but make use of our knowledge effectively—and in time.

It is a book that everyone who understands what "the land" means to America will read with comprehension and appreciation. (J. D. L.)

AGRONOMIC AFFAIRS

THE MARBUT MEMORIAL

THE committee charged with the preparation and publication of a memorial volume dedicated to the late Doctor Curtis Fletcher Marbut announces the completion of their task and states that the volume will be off the press in October and will be offered for sale for the first time at the annual meeting of the Soil Science Society in St. Louis in November. The book will be $6\frac{3}{4} \times 10$ inches in size, will contain about 300 pages, and will have 12 full-page illustrations.

The volume opens with an interesting life history of Doctor Marbut prepared by his eldest daughter, Mrs. L. Moomaw. This is followed by 12 brief sketches appraising Doctor Marbut's work prepared by his associates and contemporaries both here and in Europe. The major part of the book will consist of the more important original papers by Doctor Marbut followed by abstracts of many of his other contributions.

The book should be of particular interest to pedologists and to geographers, as well, since many of the papers are on soil geography. The development of modern soil science in America is definitely associated with Doctor Marbut's work. The memorial volume will also be a valuable reference from a historical point of view in the study of soils.

Further information about this book may be obtained at the St. Louis meeting or by writing to Professor H. H. Krusekopf, Department of Soils, University of Missouri, Columbia, Mo.

HOTEL RESERVATION IN ST. LOUIS

THE local committee in charge of arrangements for the meetings in St. Louis, November 11 to 13, recommend that hotel reservations be made well in advance of the meetings.

Single rooms at the Statler Hotel, the headquarters hotel, will run about \$3.00, with the Jefferson, Mayfair, and Lennox hotels about the same. The DeSoto and Mark Twain hotels, located near the Statler, quote rates of \$2.50 to \$2.75 single. Rates less than \$2.00 single and family rates for three to four in a room are available at the American, Maryland, Majestic, Warwick, and York hotels, all within walking distance of the Statler. Many other hotels are available at greater distances.

For further details about hotels and other local arrangements, write to Doctor Wm. A. Albrecht, Department of Soils, University of Missouri, Columbia, Mo.

THE PROGRAM FOR SECTION O OF THE A. A. A. S.

THE New York meeting of Section O of the A. A. A. S. will consist of a joint program of the Section on Agriculture with the American Society for Horticultural Science devoted to the subject of "Nutrition". The session will be held Wednesday morning, December 30, at Hunter College, New York City.

The following papers will be presented: "Nutritional Requirements of Animals: Some Deficiencies Coming Through the Soils and Crops", by Dr. L. A. Maynard, School of Nutrition, Cornell University; "Nutritional Requirements of Man: Vitamins—The More Recent Developments", by C. A. Elvehjem, Department of Biochemistry, University of Wisconsin; "Field Crop Production for Efficient Feeding", by Dr. Richard Bradfield, Department of Agronomy, Cornell University, retiring Vice President for Section O; "Fruit and Vegetable Production for Efficient Feeding", by Dr. J. R. Magness, U. S. Horticultural Station, Beltsville, Md.; and "Utilization of Foods in the Human Diet," by Dr. Lydia Roberts, Department of Home Economics, University of Chicago.

NEWS ITEMS

DOCTOR NATHAN S. HALL of the Agronomy Department of the North Carolina State College has accepted a position as Assistant

Professor and Research Assistant in the Soil Science Department of the Michigan State College.

—A—

DOCTOR SAMUEL B. ALDRICH, former Instructor in Agronomy at Ohio State University, has been appointed Extension Assistant Professor in Agronomy at the New York State College of Agriculture. In his new position Doctor Aldrich has charge of the cooperative projects of the Agronomy Department with the T.V.A. in addition to working on the regular Agronomy Extension program. He fills a position left vacant by R. B. Child.

—A—

THE IMPERIAL BUREAU OF SOIL SCIENCE of Harpenden, Herts., England, announces the publication of Technical Contribution No. 41 entitled, "The Take-all Disease of Cereals", by S. D. Garrett. The 40-page pamphlet may be obtained for two shillings and sixpence from the Central Sales Branch, Imperial Agricultural Bureau, Agricultural Research Building, Penglais, Averystwyth, Great Britain.

—A—

DOCTOR MARCUS D. WELDON, in charge of the Soils Division of the Department of Agronomy at the University of Nebraska, has been called into active military service as a Reserve Officer. Doctor Weldon is stationed at Camp Robinson, Little Rock, Ark., in the Chemical Warfare Division.

—A—

LT. LEWIS S. EVANS, formerly in charge of the bindweed research at the University of Nebraska in cooperation with the U. S. Dept. of Agriculture, is now in the service at Fort Warren, Wyo., 2nd Reg. Q.M.R.T.C. Mr. Noel S. Hanson of the University of Minnesota has been appointed to fill the vacancy.

—A—

THOMAS E. BRINEGAR, Instructor and Research assistant in Range Management at the Nebraska College of Agriculture, has reported to the Graduate School of Business Administration at Harvard University where he will receive 16 months training and will then receive a commission as a Reserve Officer in the Quartermaster's Corps.

—A—

THE AMERICAN SOCIETY FOR HORTICULTURAL SCIENCE announces that two awards of $500 each, to be known as the Vaughan Research Awards in Horticulture, will be made at the meeting of the Society in New York City, December 29 to 31, 1942. One award will be made in the field of floriculture and one in vegetable crops and the selection will be made from papers published in the PROCEEDINGS of that Society during 1942.

JOURNAL
OF THE
American Society of Agronomy

VOL. 34 NOVEMBER, 1942 NO. 11

THE INFLUENCE OF PERIODIC CLOSE GRAZING AND PASTURE FERTILIZATION UPON EROSION CONTROL[1]

D. B. JOHNSTONE-WALLACE, JOHN S. ANDREWS, AND JOHN LAMB, JR.[2]

GRASS occupies approximately 63% of the agricultural land of New York State, and 80% of the farm income is derived from the sale of milk and livestock products. In general, the pastures are located in fields which, because of their slope or for some other reason, are least suitable for the growing of other crops.

Erosion surveys indicate that some pastures have very thin swards that provide only limited protection against erosion. These are usually due to low fertility as a result of previous cropping and erosion and inadequate attention to pasture improvement and management. Pasture growth takes place rapidly during May and early June, but high temperatures combined with low soil moisture seriously restrict production in most seasons between mid-June and mid-August.

Experimental work at Cornell University, commenced by Johnstone-Wallace[3] in 1932, has shown that it is possible to maintain a dense and productive sward of grass and wild white clover by adequate fertilization combined with periodical close grazing. Wilson[4] has shown that this partial defoliation results in the release of nitrogen from the clover root nodules with beneficial results to the grasses.

The investigation reported here was designed to test the effectiveness of similar management practices on soil and water conservation under the severe climatic conditions prevailing at high altitudes in southern New York. The experiments were established at the Arnot Soil Conservation Research Station, which is located 17 miles southwest of Ithaca, N. Y., at an elevation of 1,900 feet.

[1]Contribution from the Office of Research, Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with the Cornell Agricultural Experiment Station. Received for publication December 9, 1941.

[2]Assistant Prof. of Agrostology, Cornell University; and Assistant Soil Technologist and Project Supervisor, Soil Conservation Service, U. S. Dept. of Agriculture, respectively.

[3]JOHNSTONE-WALLACE, D. B. Pasture improvement and management. Cornell Univ. Agr. Exp. Sta. Bul. 393. 1938.

———. The influence of wild white clover on the seasonal production and chemical composition of pasture herbage, and upon soil temperature, soil moisture and erosion control. Rpt. Fourth Int. Grassland Congress, Aberystwth, Great Britian: 188–196. 1937.

[4]WILSON, J. K. The loss of nodules from legume roots and its significance. Jour. Amer. Soc. Agron., 34:460–471. 1942.

The soil is Lordstown flaggy silt loam and Bath flaggy silt loam, both of which are typical of several million acres in central and southern New York and northern Pennsylvania. They are well drained and absorptive, but the Lordstown is usually shallow, while the Bath is deep.

The field selected for the experiments had been farmed for approximately 70 years, and old deposits of top soil in the forest at the lower edge of the field showed that considerable erosion had taken place.

For several years previous to the experiments, the land had been well farmed by a competent operator, erosion-resisting crops had been grown, and sufficient lime and phosphorus applied to maintain a fertility level somewhat above the average for these soils. The entire field was in oats in 1934, and in the fall of that year it was plowed and seeded to rye.

The site chosen for series D has a southeast exposure with a 23% slope and received little afternoon sun. As the prevailing winds come from the northwest, the plots in series D are usually covered with snow drifts for several months during the winter. This often prevents freezing of the soil and at the same time provides an abundant supply of moisture during early spring. Series C above and to the north of the D series had the same exposure and extended to the hilltop with a slope of approximately 11%. It received more sunshine and wind and was never covered with snow drifts.

METHODS

Two series of plots, C and D, were established late in 1934 and early in 1935. The C series consisted of three ½-acre pastured plots (Fig. 1a). The runoff was collected from a section 160 feet long and 64 feet wide surrounded by steel border plates. The water and soil were caught in covered tanks at the base of the plots.

Before seeding, fertilizer was broadcast and worked into the surface at the following rates per acre: Fine ground limestone, 2,000 pounds; 16% superphosphate, 800 pounds; and muriate of potash, 100 pounds. In the fall of 1938 these plots again received a surface application of 16% superphosphate at the rate of 800 pounds per acre. All plots of the series were seeded on May 13, 1935, with the following mixture:

Kentucky bluegrass (*Poa pratensis*)	9 pounds per acre
Perennial ryegrass (*Lolium perenne*)	5 pounds per acre
Rough stalked meadow grass (*Poa trivialis*)	1 pound per acre
Kent wild white clover (*Trifolium repens*)	1 pound per acre

Series D consisted of four groups of plots each group consisting of ½ acre pastured area divided into smaller replicated 1/100-acre plots (Fig. 1b). The lower tier of 1/100-acre plots were separated by steel border plates that projected 4 inches above the soil surface and penetrated to a depth of 8 inches below. All runoff water from three plots within each group was caught in covered tanks at the base of the plots. Series 100 and 400 were limed and fertilized in the same manner as plots C 1 and C 3. Series 200 and 300 were left untreated.

On May 2, 1935, each plot of the D series was seeded to the grass listed later in Table 1 at the rate of 24 pounds per acre. In addition series D 100 and D 300 plots were seeded to Kent wild white clover at the rate of 2 pounds per acre.

All plots were closely grazed by sheep. These were weighed when turned into the plots and when removed. The yield of herbage was obtained from under steel cages measuring 2 feet by 2 feet by 9 inches high, one on each lower tier plot of series D and five on each plot of series C. The grass was cut to the grazed height of approximately ½ inch from the ground surface and the cage moved to a new location after each cutting, care being taken to select an area as representative of

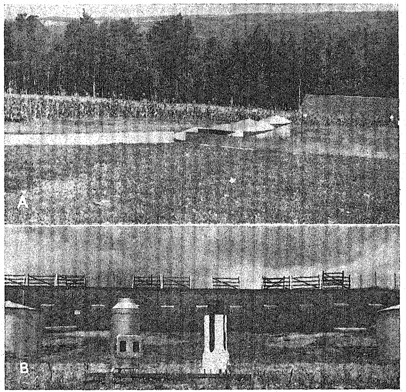


FIG. 1.—A, plot 3C catchment equipment, pasture sward in the foreground is the Cornell pasture mixture, limed and fertilized, and closely grazed. Season early September. B, general view of plots in series D100. Season early spring.

the entire plot as possible. Botanical analyses were made by separating the grasses and clovers while still fresh and drying them to constant weight at 105° C. No grazing was done during the year of seeding, but the plots were clipped with a lawn mower. Wild white clover volunteering in series D 200 and D 400 was removed until 1939.

RESULTS

The fertilized plots of grass and clover made a more vigorous growth than the unfertilized plots and were ready to graze earlier each spring. Their increased yields are reflected in the average yield

of dry matter shown in Tables 1 and 2. The effect of this better growth on runoff and soil loss is shown in Table 3.

Perennial ryegrass established itself very rapidly and provided effective control early in the year of seeding. It persisted well in the fertilized plots containing wild white clover, but soon disappeared from those left without clover or without lime and fertilizer (Figs. 3a and 3b).

TABLE 1.—*Average yield of dry matter and average and annual percentage of clover for selected grasses with different soil treatments.*

Plot No.	Grass*	Av. dry weight per acre per year, lbs.	Clover in herbage, % 1936	1937	1938	1939	Av., 1936–39
	Grass and Clover Limed and Fertilized						
D 101	Kentucky bluegrass	3,003	43.4	40.3	28.9	0.5	28.3
2	Canada bluegrass	3,183	70.1	30.4	52.0	2.9	38.9
3	Redtop	3,922	25.2	26.7	24.7	12.1	22.2
4	Colonial bent	3,226	57.3	27.1	43.1	41.4	42.2
5	Seaside creeping bent	3,563	39.8	28.8	39.6	33.3	35.4
6	Timothy S 50 pasture	3,026	54.2	38.4	70.4	41.7	51.2
7	Timothy	3,147	19.3	15.9	46.3	63.5	36.3
8	Orchard grass	3,748	5.8	15.2	11.8	9.5	10.6
9	Poverty oat grass	2,844	96.5	55.3	76.8	27.6	64.1
10	Perennial ryegrass	4,035	28.9	20.7	89.2	6.1	36.2
	Average	3,370	44.1	29.9	48.3	23.9	36.5
	Grass Alone; Not Limed or Fertilized						
D 201	Kentucky bluegrass	1,155	0.0	0.0	0.0	0.0	0.0
2	Canada bluegrass	1,240	0.0	0.0	0.0	0.5	0.1
3	Redtop	1,204	0.0	0.0	0.0	0.0	0.0
4	Colonial bent	1,219	0.0	0.0	0.0	0.0	0.0
5	Seaside creeping bent	1,354	0.0	0.0	0.0	1.3	0.3
6	Timothy S 50 pasture	1,215	0.0	0.0	0.0	2.1	0.5
7	Timothy	1,441	0.0	0.0	0.0	0.0	0.0
8	Orchard grass	1,456	0.0	0.0	0.0	0.0	0.0
9	Poverty oat grass	1,730	0.0	0.0	0.0	0.0	0.0
10	Perennial ryegrass	1,142	0.0	0.0	0.0	0.0	0.0
	Average	1,316	0.0	0.0	0.0	0.2	0.1
	Grass and Clover; Not Limed or Fertilized						
D 301	Kentucky bluegrass	1,383	46.8	5.5	0.0	0.0	13.1
2	Canada bluegrass	1,961	43.6	5.3	0.0	0.0	12.2
3	Redtop	1,957	16.4	6.2	0.0	0.0	5.7
4	Colonial bent	1,961	31.8	11.8	2.4	0.2	11.6
5	Seaside creeping bent	1,254	5.1	0.7	7.0	0.3	3.3
6	Timothy S 50 pasture	2,124	20.6	14.7	9.4	0.2	11.2
7	Timothy	1,880	14.0	2.9	0.3	0.0	4.3
8	Orchard grass	1,730	4.7	4.2	2.2	0.0	2.8
9	Poverty oat grass	2,007	24.0	7.3	2.1	0.0	8.4
10	Perennial ryegrass	1,804	19.8	14.9	0.0	0.4	8.8
	Average	1,806	22.7	7.4	2.3	0.1	8.1

TABLE 1.—*Concluded.*

Plot No.	Grass*	Av. dry weight per acre per year, lbs.	Clover in herbage, %				
			1936	1937	1938	1939	Av., 1936–39
	Grass Alone Limed and Fertilized						
D 401	Kentucky bluegrass	1,439	0.0	0.0	0.0	10.0	2.5
2	Canada bluegrass	1,712	0.0	0.0	0.0	0.7	0.2
3	Redtop	1,624	0.0	0.0	0.0	1.1	0.3
4	Colonial bent	1,334	0.0	0.0	0.0	0.0	0.0
5	Seaside creeping bent	1,218	0.0	0.0	0.0	4.3	1.1
6	Timothy S 50 pasture	1,202	0.0	0.0	0.0	0.8	0.2
7	Timothy	1,709	0.0	0.0	0.0	14.1	3.5
8	Orchard grass	1,490	0.0	0.0	0.0	0.0	0.0
9	Poverty oat grass	2,647	0.0	0.0	0.0	0.0	0.0
10	Perennial ryegrass	1,283	0.0	0.0	0.0	0.3	0.1
	Average	1,566	0.0	0.0	0.0	3.1	0.8

*Botanical names in order of listing are as follows: *Poa pratensis*, *P. compressa*, *Agrostis alba*, *A. tenuis*, *A. palustris*, *Phleum pratense* var., *P. pratense*, *Dactylis glomerata*, *Danthonia spicata*, and *Lolium perenne*.

The stoloniferous habit of growth of wild white clover resulted in the development of a dense protective sward in all the grass plots in which it was seeded, provided these received lime and fertilizer treatment. Little surface soil was exposed and no appreciable loss of soil or water took place, even during exceptionally heavy rains.

Series D 400, which received mineral fertilizer treatment but no wild white clover seeding, made no more growth than the unfertilized plot without clover. It is evident here, as is usually the case, that in the absence of legumes the growth of the grasses was limited by a deficiency of nitrogen (Tables 1 and 2).

In 1939 the rainfall for May, June, and July was only about 50% of normal. The wild white clover and most of the grasses were seriously injured. In spite of this, the mat of dry plant material on the surface provided sufficient protection so that when fairly heavy thunderstorms occurred later there was extremely little loss of water and no appreciable loss of soil (Table 4).

On the whole, Kentucky bluegrass and wild white clover, fertilized, provided the most dense cover (Fig. 2a). Although Kentucky bluegrass was somewhat slower in becoming established than either perennial ryegrass or redtop, it suffered considerably less injury during periods of drought. It was able to become dormant during such periods and to recover rapidly as soon as sufficient rain occurred.

Redtop, Colonial bent, and Seaside creeping bent, as well as commerial timothy and S 50 timothy, suffered greatest injury in the drought of 1939. Prior to this, commercial timothy was practically eliminated by periodical close grazing, whereas the S 50 timothy continued to flourish and produced a good sward. The timothy varieties because of their high palatability were more closely grazed than the other grasses. Orchard grass made a better growth than the other grasses during periods of drought.

TABLE 2.—*Annual and average yield of dry matter, percentage of clover, and sheep live weight gains for different soil treatments.*

Series No.	Treatment	Cover	Dry weight pasture herbage, lbs. per acre					Av. % clover content 1936–39	Sheep live weight gains, lbs. per acre				
			1936	1937	1938	1939	1936–39 Av.		1936	1937	1938	1939	Av. 1936–39
100	Superphosphate, potash, lime	Grass and clover	5,076	4,624	1,954	1,826	3,370	36.5	490	62	301	94	237
200	None	Grass	1,892	1,905	891	573	1,315	0.1	144	−7	114	41	73
300	None	Grass and clover	2,138	2,874	1,173	1,039	1,806	8.1	310	122	161	67	165
400	Superphosphate, potash, lime	Grass	1,821	2,501	1,000	941	1,566	0.8	291	9	142	4	112

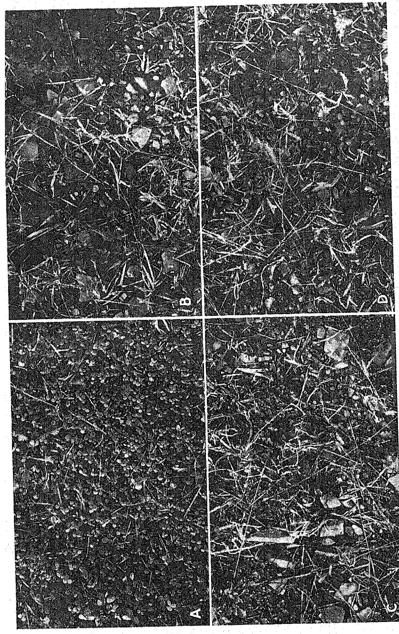


FIG. 2.—A, plot D101, Kentucky bluegrass and wild white clover, fertilized. B, plot D201, Kentucky bluegrass alone, unfertilized. C, plot D301, Kentucky bluegrass and wild white clover, unfertilized. D, plot D401, Kentucky bluegrass alone, fertilized.

Poverty oat grass was unable to compete with wild white clover on the fertilized plots and there made a very poor showing. On the unfertilized plots, however, it grew slowly and finally provided a more dense cover than any of the other grasses, but it did not produce a satisfactory type of pasture because of low palatability (Fig. 3).

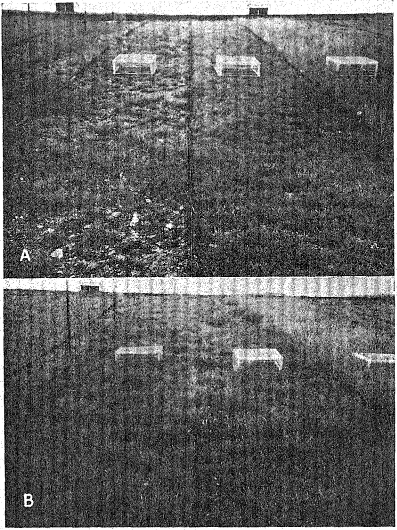


FIG. 3.—A, left, perennial ryegrass; right, poverty oat grass, not fertilized. Spring of 1939. B, left, perennial ryegrass; right, poverty oat grass, fertilized and grown with wild white clover. Spring of 1939.

Although there was considerable variation in the type of sward produced by the grasses and mixtures used under different methods of

TABLE 3.—*Soil and water losses June 18, 1936, rainfall 1.4 inches, intensity of rainfall 1.0 inch in 10 minutes.*

Plot No.	Slope, %	Treatment	Runoff, %	Soil loss per acre, lbs.
D 104	23	Colonial bent grass plus wild white clover fertilized with superphosphate, potash, and lime	0.5	3
D 204	23	Colonial bent grass not fertilized	8.1	267
A 8	19	Bare soil	48.7	17,141

fertilizer treatment or grazing management, practically no soil loss occurred once the plants were well established, and the loss of water by runoff from the surface was very small, except when the soil was frozen as illustrated by the results in Table 5. The adjacent cultivated and bare soil plots, however, lost a considerable amount of both water and soil. It is evident that a pasture cover may be poor from the standpoint of edible herbage yet have sufficient weeds and stones to provide effective erosion control. Other experiments on the station have indicated that surface stones alone reduce runoff and decrease soil loss. The cover on the unfertilized plots was more dense than that found on many poor farm pastures. This was probably the result of previous fertilizer treatment and protection from the afternoon sun.

TABLE 4.—*Soil and water losses August 4, 1939, rainfall 2.75 inches, intensity of rainfall 0.5 inch in 10 minutes.*

Plot No.	Slope, %	Treatment	Runoff, %	Soil loss per acre, lbs.
D 101	23	Kentucky bluegrass plus wild white clover fertilized with superphosphate, potash, and lime	0.2	0
A 8	19	Bare soil	19.2	2,262

The fertilized plots that contained wild white clover gave consistently higher yields of herbage throughout the grazing season than the unfertilized plots or those containing no wild white clover. However, production during periods of hot dry weather in July and August was low, especially in the abnormally dry years of 1936 and 1939. In general, the live weight gains made by the sheep followed the yields of herbage obtained from the cages (Table 2), but there are indications that the feeding value of the dry matter was improved by the lime and fertilizer applications and by the addition of clover.

In series C, plots C 2 and C 3 were heavily stocked and closely grazed beyond the stage at which maximum live weight gains would be expected (Fig. 4). In spite of this it will be seen from Table 6 that plot C 3, fertilized and heavily grazed, lost extremely little soil or water and produced the greatest live weight gains per acre. Plot C 1, which was fertilized and deliberately understocked and undergrazed, produced a growth of tall herbage that suppressed all legumes after the first year, except in the small areas which the sheep, of their own

Poverty oat grass was unable to compete with wild white clover on the fertilized plots and there made a very poor showing. On the unfertilized plots, however, it grew slowly and finally provided a more dense cover than any of the other grasses, but it did not produce a satisfactory type of pasture because of low palatability (Fig. 3).

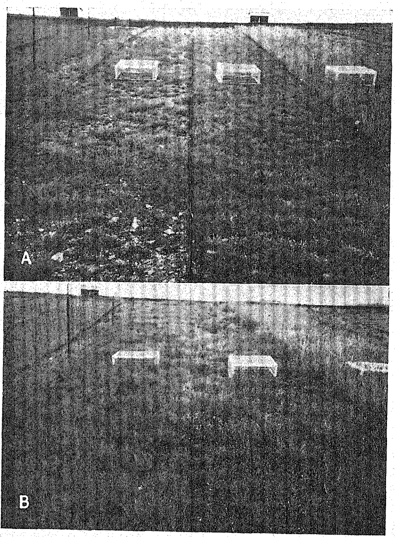


FIG. 3.—A, left, perennial ryegrass; right, poverty oat grass, not fertilized. Spring of 1939. B, left, perennial ryegrass; right, poverty oat grass, fertilized and grown with wild white clover. Spring of 1939.

Although there was considerable variation in the type of sward produced by the grasses and mixtures used under different methods of

TABLE 3.—*Soil and water losses June 18, 1936, rainfall 1.4 inches, intensity of rainfall 1.0 inch in 10 minutes.*

Plot No.	Slope, %	Treatment	Runoff, %	Soil loss per acre, lbs.
D 104	23	Colonial bent grass plus wild white clover fertilized with superphosphate, potash, and lime	0.5	3
D 204	23	Colonial bent grass not fertilized	8.1	267
A 8	19	Bare soil	48.7	17,141

fertilizer treatment or grazing management, practically no soil loss occurred once the plants were well established, and the loss of water by runoff from the surface was very small, except when the soil was frozen as illustrated by the results in Table 5. The adjacent cultivated and bare soil plots, however, lost a considerable amount of both water and soil. It is evident that a pasture cover may be poor from the standpoint of edible herbage yet have sufficient weeds and stones to provide effective erosion control. Other experiments on the station have indicated that surface stones alone reduce runoff and decrease soil loss. The cover on the unfertilized plots was more dense than that found on many poor farm pastures. This was probably the result of previous fertilizer treatment and protection from the afternoon sun.

TABLE 4.—*Soil and water losses August 4, 1939, rainfall 2.75 inches, intensity of rainfall 0.5 inch in 10 minutes.*

Plot No.	Slope, %	Treatment	Runoff, %	Soil loss per acre, lbs.
D 101	23	Kentucky bluegrass plus wild white clover fertilized with superphosphate, potash, and lime	0.2	0
A 8	19	Bare soil	19.2	2,262

The fertilized plots that contained wild white clover gave consistently higher yields of herbage throughout the grazing season than the unfertilized plots or those containing no wild white clover. However, production during periods of hot dry weather in July and August was low, especially in the abnormally dry years of 1936 and 1939. In general, the live weight gains made by the sheep followed the yields of herbage obtained from the cages (Table 2), but there are indications that the feeding value of the dry matter was improved by the lime and fertilizer applications and by the addition of clover.

In series C, plots C 2 and C 3 were heavily stocked and closely grazed beyond the stage at which maximum live weight gains would be expected (Fig. 4). In spite of this it will be seen from Table 6 that plot C 3, fertilized and heavily grazed, lost extremely little soil or water and produced the greatest live weight gains per acre. Plot C 1, which was fertilized and deliberately understocked and undergrazed, produced a growth of tall herbage that suppressed all legumes after the first year, except in the small areas which the sheep, of their own

TABLE 5.—*Soil and water loss under two systems of pasture management.*

Plot No.	Period	Treatment*	Precipitation, in.	Runoff Inches	Runoff %	Soil loss per acre, lbs.
D 101	1936, July–Oct.	Grass and clover fertilized	13.7	—	0.2	5
D 201	1936, July–Oct.	Grass alone unfertilized	13.7	0.4	3.0	347
D 101	1937, May–Oct.	Grass and clover fertilized	31.0	0.1	0.2	—
D 201	1937, May–Oct.	Grass alone unfertilized	31.0	0.1	0.3	—
D 101	1938, May–Oct.	Grass and clover fertilized	20.7	0.1	0.6	—
D 201	1938, May–Oct.	Grass alone unfertilized	20.7	0.1	0.6	—
D 101	1939, May–Oct.	Grass and clover fertilized	16.7	—	0.2	—
D 201	1939, May–Oct.	Grass alone unfertilized	16.7	0.1	0.3	—
D 101	Total	Grass and clover fertilized	82.1	0.2	0.3	5
D 201	Total	Grass alone unfertilized	82.1	0.7	0.8	347
D 101	1936–37, Nov.–Apr.	Grass and clover fertilized	18.7	4.4	23.4	—
D 201	1936–37, Nov.–Apr.	Grass alone unfertilized	18.7	8.7	46.5	—
D 101	1937–38, Nov.–Apr.	Grass and clover fertilized	14.2	7.3	51.6	—
D 201	1937–38, Nov.–Apr.	Grass alone unfertilized	14.2	7.9	56.1	—
D 101	1938–39, Nov.–Apr.	Grass and clover fertilized	15.1	0.7	4.3	—
D 201	1938–39, Nov.–Apr.	Grass alone unfertilized	15.1	1.6	10.6	—
D 101	Total	Grass and clover fertilized	48.0	12.3	25.7	—
D 201	Total	Grass alone unfertilized	48.0	18.2	38.0	—

*Plot D 101, Kentucky bluegrass and wild white clover fertilized with superphosphate, potash, and lime; plot D 201, Kentucky bluegrass alone not fertilized.

accord, kept closely grazed. Thus, even this plot was closely grazed in parts due to the feeding habits of the animals. There was slightly more loss of water and slightly less loss of soil than on the closely

TABLE 6.—*Effects of various systems of pasture management on soil and water losses, yield dry matter, and sheep live weight gains.*

Plot No.*	Treatment	1936–37 Total dry matter, lbs. per acre	1936–37 Sheep live weight gains, lbs. per acre	Total runoff and soil loss July through October 1936 and May through October 1937† Runoff Inches	Runoff %	Soil loss lbs. per acre
C 1	Lightly grazed and fertilized with superphosphate, potash, and lime	16,702	508	0.38	0.9	26
C 2	Heavily grazed, not fertilized	7,570	456	0.79	1.8	163
C 3	Heavily grazed and fertilized with superphosphate, potash, and lime	10,893	618	0.20	0.5	67

*Slope C 1, 10%; C 2, 11%; C 3, 12%.
†Total rainfall 43.57 inches.

grazed plot, but the differences are considered doubtfully significant. The more open sward of plot C 2, which was not limed or fertilized

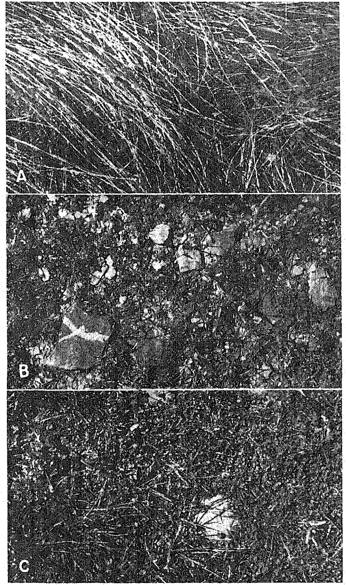


FIG. 4.—A, plot C1. Cornell pasture mixture, fertilized and undergrazed. B, plot C2. Cornell pasture mixture, unfertilized and closely grazed. C, plot C3. Cornell pasture mixture, fertilized and closely grazed.

but heavily stocked and closely grazed, resulted in what is probably a significantly greater loss of soil and water.

The water loss was so small from both series D and C, especially in the case of the fertilized grass and clover plots, that additional control measures such as contour furrows could have been of little practical value.

SUMMARY

Under conditions of favorable fertility resulting from adequate lime and fertilizer treatment and the inclusion of wild white clover, the following results were observed:

1. Various grasses in association with the clover provided almost complete control of erosion and allowed little loss of water when the soil was not frozen.
2. Periodical close grazing did not increase erosion or loss of water, but tended to result in the development of a protective type of sward of grass and clover. The returns in live weight gains per acre were increased in comparison with those obtained from a system of light grazing and stocking.
3. Kentucky bluegrass and clover gave the most satisfactory type of pasture under the system of grazing management used.
4. Perennial ryegrass produced a protective sward first after seeding.

Under conditions of less favorable fertility where no lime and fertilizer was used, the following results were observed:

1. The type of pasture sward developed was unsatisfactory from the point of view of productivity and somewhat less effective in controlling erosion.
2. Redtop produced a protective sward first.
3. Poverty grass provided the thickest cover and the greatest yield of herbage, but the herbage was unpalatable.

Lime and fertilizer treatment in the absence of clover produced a sward little better than the sward with no clover which was neither limed nor fertilized.

SOIL LIMING INVESTIGATIONS: VI. RESPONSE OF CRIMSON CLOVER TO BORON WITH AND WITHOUT LIME ON COASTAL PLAINS SOILS[1]

JAMES A. NAFTEL[2]

THE value of winter legumes for soil improvement has been recognized for many years, especially in the Southeast where nitrogen and organic matter contents of soils are extremely low. There have been many attempts to establish winter legume programs by agricultural leaders in this section. Much progress has been made in Alabama on the use of winter legumes as shown by the fact that in 1940 more than 20 million pounds of seed were planted. Nearly all of the seed was purchased out of the state.

Winter legumes have not been as widely accepted and as successfully grown in the Southeast as the need warrants. The main reasons for this are that winter legumes have not consistently produced satisfactory yields, and that these crops often do not produce seed in sufficient amounts to warrant harvesting. Crimson clover is a winter legume that seeds abundantly in the Southeast wherever the crop can be grown successfully. It has not been a dependable crop, however, and its use is seldom recommended in the Lower Coastal Plains.

It is clear that for a successful winter legume program it is desirable to have a crop which can be depended upon both for successful vegetative yields and seed production. The purpose of this study was to determine the possible need for boron in combination with lime and fertilizers for growing crimson clover on Coastal Plains soils.

REVIEW OF LITERATURE

In a report made in 1898, Duggar (5)[3] showed the possibility of growing relatively high yields of crimson clover where proper inoculation and fertilizers were used. He stated, "It is almost certain that crimson clover has failed more frequently and more completely than any other plant ever tested in Alabama". These failures were due, in his opinion, mainly to inoculation failures. Trials of crimson clover have been made in different sections of Alabama (3), but this crop has not been successfully grown year after year in the lower Coastal Plains as it has been in the northern part of the state.

Hollowell (6) states that crimson clover is the most important annual winter legume in the central section of the southeastern United States and points out that this crop has the distinct advantage of being a heavy producer of seed. It has been reported (1) that crimson clover is adapted to soils such as those of the Piedmont Plateau of Georgia which contain considerable amounts of clay. Crimson clover is well adapted to Tennessee conditions and is equal to red clover for soil improvement (8).

As far as known, there are no references in the literature to the requirements

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director as Part VI of a series. Received for publication June 1, 1942.

[2]Associate Soil Chemist.

[3]Figures in parenthesis refer to "Literature Cited", p. 985.

of crimson clover for boron, although there are numerous reports of the requirements for boron of alfalfa, red clover, and other legumes (2, 4, 7, 9, 10, 11, 12).

PLAN OF INVESTIGATION

In the course of conducting greenhouse culture experiments involving the addition of lime and boron to soils, crimson clover was grown as one of the winter test crops in several experiments. These studies were begun in the fall of 1938 and are being continued.

The greenhouse culture experiments were conducted in the usual manner, using only surface soils. The soil was passed through a ¼-inch screen and 8 or 9 kilograms of air-dry soil were placed in 2-gallon glazed pots. In general, fertilizer salts and B were applied in solution for the successive crops grown in duplicate soil cultures.

RESULTS

Crimson clover was grown in several independent experiments over a 4-year period and each of these will be reported and discussed separately.

RESIDUAL EFFECTS OF BORON, LIME, AND FERTILIZERS ON GROWTH AND FLOWERING

Crimson clover was planted in the fall of 1938 as the third successive crop on a Norfolk sandy loam which had received various increments of lime and in which existed residual effects of different sources of N. Borax was added to some of the cultures prior to the first crop at the rate of 15 pounds per acre, as shown in Table 1. These B treat-

TABLE 1.—*Green weights of crimson clover with and without borax and soil reaction as influenced by residual effects of source of N and lime on Norfolk sandy loam.*

Pot No.	Source of N	Boron added	Results	Liming as percentage Ca saturation				
				Native	50	75	100	150
1	None	No	Yield, grams pH	11.60 4.8	46.45 5.7	44.30 6.2	27.60 6.9	14.10 7.1
2	$(NH_4)_2SO_4$	No	Yield, grams pH	0.20 3.9	28.15 5.0	40.15 5.8	— —	48.10 7.0
3	$(NH_4)_2SO_4$	Yes	Yield, grams pH	0.70 3.9	34.70 5.0	70.15 5.7	— —	96.75 7.1
4	$NaNO_3$	No	Yield, grams pH	40.05 5.6	52.85 6.3	— —	— —	44.85 7.4
5	$NaNO_3$	Yes	Yield, grams pH	33.50 5.7	94.25 6.1	— —	— —	81.40 7.5
6	Vetch	No	Yield, grams pH	21.20 4.8	66.75 5.5	— —	— —	91.65 7.0
7	Vetch	Yes	Yield, grams pH	18.20 4.8	74.20 5.3	— —	— —	84.65 7.0

ments were not repeated, thus the crimson clover had access only to residual B. After the crimson clover was thinned to an even stand, 200 pounds per acre of KH_2PO_4 were added to supply P and K. Yields of this crop are included in Table 1, as are also the pH values of the soils, determined immediately after the crimson clover was harvested.

In the case of cultures which did not receive N or B, the yields reached a maximum near pH 6.0 and were severely depressed at pH 7.1. A favorable response to lime as well as an over-liming effect were evident in this crop. Where NH_4N was added, the acidity of the soil increased; and when no B was applied, the yields were directly proportional to the amount of lime added. After the addition of B, however, the yields were practically doubled at both the moderate and highest rates of lime. Slight over-liming resulted where $NaNO_3$ was added without B, but when B was applied the crop responded favorably to both lime and B. Where vetch in the form of green manure was applied earlier as a source of N, there was a large increase in yield of crimson clover from liming the soil and practically no response to B.

In another experiment boron in concentrations from 0 to 1.5 p.p.m. in increments of 0.3 p.p.m. B was applied to a Norfolk sandy loam soil. Crimson clover was planted in the fall of 1938 as the third successive crop, the soils having been treated with boron, lime, and fertilizer prior to the first crop.

During the flowering stage of the crimson clover, it was observed (Fig. 1) that the B and lime treatments were affecting the time and number of blooms. These observations are recorded in Table 2 and show that the greatest number of flower heads were borne on the plants which received 0.3 p.p.m. B and limed to 150% Ca saturation. There were no flowers present at this stage of growth where the soil was treated with more than 0.9 p.p.m. B, except in one instance.

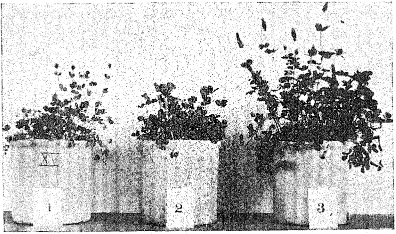


FIG. 1.—Effect of lime and boron on flower development and growth of crimson clover. No. 1, unlimed; No. 2, limed to 50%; and No. 3, limed to 150% Ca saturation, all with 0.3 p.p.m. B.

TABLE 2.—*Effect of adding different concentrations of boron and lime to Norfolk sandy loam on the development of flowers on crimson clover.*

Pot No.	Borax treatments, p.p.m. B	Liming as percentage Ca saturation								
		Native			50			150		
		1	2	Av.	1	2	Av.	1	2	Av.
1	0.0	1*	5	3.0	8	5	6.5	6	16	11.0
2	0.3	10	10	10.0	8	8	8.0	21	20	20.5
3	0.6	9	6	7.5	2	1	1.5	8	1	4.5
4	0.9	0	0	0.0	4	7	5.5	0	0	0.0
5	1.2	0	0	0.0	0	0	0.0	0	2	1.0
6	1.5	0	0	0.0	0	0	0.0	0	0	0.0

*Number of flowers per pot.

The greatest effect of B on this crop was in its influence on weight of green matter (Table 3). Where B was not added, relatively small yields were obtained on the unlimed soil and considerable increases were obtained where the soil was limed. The addition of 0.3 p.p.m. B gave more than a threefold increase in yield where the lime was added at 150% Ca saturation and doubled the yield at 50% Ca saturation. Boron had little effect on the growth of the clover on the unlimed soil except where 1.5 p.p.m. B were applied. At this concentration the B was toxic.

TABLE 3.—*Effect of adding different concentrations of boron and lime to Norfolk sandy loam on yields of crimson clover.*

Pot No.	Borax treatments, p.p.m. B	Liming as percentage Ca saturation		
		Native	50	150
1	0.0	24.65*	34.40	46.55
2	0.3	26.35	72.45	156.25
3	0.6	26.65	55.20	91.50
4	0.9	24.15	70.50	157.15
5	1.2	28.60	67.85	137.00
6	1.5	19.95	88.40	129.05

*Green weights in grams; average of duplicates.

SOURCES AND RATES OF LIME WITH AND WITHOUT BORON SUPPLEMENTS ON SIX COASTAL PLAINS SOILS

In June 1939, large samples of soils were obtained from southeast Alabama for greenhouse cultures. The soils were selected as typical of the Lower Coastal Plains soil province for the purpose of determining the response to various sources of lime and supplements of B. Crops were grown on these soils in the following order: Sorghum, crimson clover, cotton, soybeans, Willamette vetch, crimson clover, and peanuts. The results to be discussed at present deal with the two crops of crimson clover. These studies were conducted in three groups of two soils each and the results will be discussed accordingly.

Five sources of lime at two rates of application on Norfolk sandy loam and Orangeburg fine sandy loam.—Soil treatments and yields of the two crops of crimson clover are given in Table 4 for each of the two soils. Small yields were obtained on the Norfolk sandy loam without lime. Moderate yields were obtained when 1 ton per acre of the various sources of lime was applied, with the exception of blast furnace slag where enormous yields resulted. It should be mentioned that the greatest response to blast furnace slag was obtained on the first successive crops. In later crops, soil acidity had increased somewhat and the crimson clover yields were considerably reduced as compared with the first crop on these soils. The 2-ton per acre rate of lime was excessive and reduced yields, except for the blast furnace slag which gave slightly greater yields.

TABLE 4.—*The effect of sources and rates of lime on successive crops of crimson clover on two Coastal Plains soils.*

Pot No.	Lime treatment		Yields in grams			
	Source	Tons per acre	Norfolk sandy loam No. 1021		Orangeburg fine sandy loam No. 1023	
			1st crop*	2nd crop†	1st crop*	2nd crop†
1–2	None	0	16.5	17.7	5.0	0.4‡
3–4	Calcitic	1	59.3	28.4	28.3	31.3‡
5–6	Calcitic	2	33.0	15.9	28.9	37.2‡
7–8	Dolomitic	1	55.0	24.2	34.1	36.1‡
9–10	Dolomitic	2	57.2	10.6	19.5	39.2‡
11–12	Ocala (soft calcitic)	1	59.0	21.1	49.4	31.6‡
13–14	Ocala (soft calcitic)	2	41.0	21.2	27.2	31.5‡
15–16	Blast furnace slag	1	104.5	35.2	101.8	23.2
17–18	Blast furnace slag	2	117.9	43.6	130.0	27.5
19–20	Paper mill waste	1	81.7	31.2	64.8	30.6‡
21–22	Paper mill waste	2	88.6	21.2	56.0	23.4‡

*First crop of crimson was the third successive crop grown on the soils.
†Second crop of crimson was the sixth successive crop grown on the soils.
‡Borax added at the rate of 15 pounds per acre.

The Orangeburg fine sandy loam was of lower fertility than the Norfolk soil and lower yields were obtained, except where the blast furnace slag was applied. Since it appeared from observation of the clover that all of the soils except that treated with blast furnace slag were deficient in some essential element, B was applied to the soil for the second crop of crimson clover on the Orangeburg fine sandy loam. As may be seen in the last column of Table 4, larger yields were obtained generally at the higher rate of lime application. Similar and more conclusive data, given below, were obtained with lime and B in companion studies of this investigation.

Three sources of lime at three degrees of fineness on a Norfolk sand and an Orangeburg loamy sand.—These soils were treated with three sources of lime in amounts equivalent to 2 tons per acre. Yields of clover are given in Table 5 and the relative growth from the various

TABLE 5.—*The effect of sources and fineness of lime on successive crops of crimson clover on two Coastal Plains soils.*

Pot No.	Lime treatment			Yields in grams			
				Norfolk sand No. 1016		Orangeburg loamy sand No. 1019	
	Source	Fineness or mesh	Pounds per acre	1st crop*	2nd crop†	1st crop*	2nd crop†
1–2	None	——	——	12.2	0.0‡	13.1	15.4
3–4	Glenco dolomitic	10–20	4,200	17.8	106.5‡	70.5	2.6
5–6	Glenco dolomitic	40–60	4,200	0.0	97.4‡	12.4	4.8
7–8	Glenco dolomitic	80–100	4,200	0.0	101.2‡	4.5	14.6
9–10	Ketona dolomitic	10–20	3,960	16.1	89.4‡	78.6	63.5‡
11–12	Ketona dolomitic	40–60	3,960	0.0	106.3‡	7.2	100.5‡
13–14	Ketona dolomitic	80–100	3,960	0.0	106.4‡	3.8	93.5‡
15–16	Blast furnace slag	10–20	6,040	78.1	54.0	86.7	65.4
17–18	Blast furnace slag	40–60	6,040	92.2	75.9	102.0	62.1
19–20	Blast furnace slag	80–100	6,040	81.5	101.6	126.0	64.6

*First crop of crimson clover was the third successive crop grown on the soils.
†Second crop of crimson clover was the sixth successive crop grown on the soils.
‡Borax added at the rate of 15 pounds per acre.

treatments of the first crop on the Orangeburg loamy sand is shown in Figs. 2 and 3, photographed before the flowering stage.

The two finer separates of lime completely inhibited growth of clover on the Norfolk sand, but the blast furnace slag at all degrees of fineness promoted abundant growth. To determine if B was deficient in this soil, 15 pounds per acre of borax were applied to the limed soils. This treatment resulted in greatly increased yields of clover.

Results obtained on the Orangeburg loamy sand were similar to those on the Norfolk soil, however, a lesser degree of B deficiency was evident on the Orangeburg soil. A further comparison of the response to B was obtained by adding borax to pots 9 to 14, inclusive, for the second crop of clover on this soil. The added B completely overcame the deficiency and large yields were obtained as compared with cultures 3 to 8.

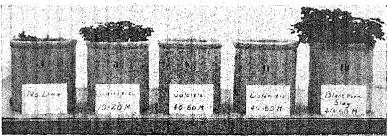


FIG. 2.—Response of crimson clover on Orangeburg loamy sand to different sources of lime.

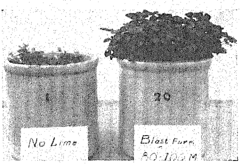


FIG. 3.—Response of crimson clover to blast furnace slag on Orangeburg loamy sand. Note chlorotic foliage and poor growth on left and normal growth on right.

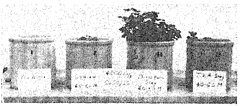


FIG. 4.—Response of crimson clover to different sources of lime on Kalmia loamy fine sand.

Three sources of lime at three rates of application on a Norfolk fine sandy loam and a Kalmia loamy fine sand.—Lime was added to these soils in amounts to give ½, 1, and 2 tons $CaCO_3$ equivalent per acre. Yield data are given in Table 6 and the relative growth on the Kalmia loamy fine sand is shown in Fig. 4.

The Nolfolk fine sandy loam responded favorably to the lower applications of lime but was over-limed when 2 tons per acre were applied. Again blast furnace slag in all applications gave much higher yields of crimson clover than any other source of lime. The T.V.A. ground slag as a source of lime gave responses similar to the dolomite since ample P was supplied to all cultures.

On the Kalmia soil, the first crop of crimson clover did not make a

TABLE 6.—*The effect of sources and rates of lime on successive crops of crimson clover on two Coastal Plains soils.*

Pot No.	Lime treatment: Source	Lime treatment: Pounds per acre	Yields in grams: Norfolk fine sandy loam No. 1024, 1st crop*	Norfolk fine sandy loam No. 1024, 2nd crop†	Kalmia loamy fine sand No. 1027, 1st crop*	Kalmia loamy fine sand No. 1027, 2nd crop†
1–2	None	0	7.1	3.5	3.4	0.0‡
3–4	Dolomitic	1,050	23.0	18.3	4.6	38.0‡
5–6	Dolomitic	2,100	24.9	21.7	0.0	23.3‡
7–8	Dolomitic	4,200	15.9	18.3	0.0	25.5‡
9–10	Blast furnace slag	1,510	77.6	16.7	92.4	4.3
11–12	Blast furnace slag	3,020	84.5	22.3	104.9	34.2
13–14	Blast furnace slag	6,040	69.5	23.5	98.5	23.2
15–16	TVA ground slag	1,266	34.4	25.7	13.1	21.7‡
17–18	TVA ground slag	2,532	16.6	22.6	0.0	24.0‡
19–20	TVA ground slag	5,064	—	—	0.0	20.7‡

*First crop of crimson clover was the third successive crop grown on the soils.
†Second crop of crimson clover was the sixth successive crop grown on the soils.
‡Borax added at the rate of 15 pounds per acre.

satisfactory growth, except where blast furnace slag was applied. Borax was added to this soil for the second crop of clover, except where blast furnace slag was applied, and satisfactory yields were obtained on the limed soils.

OTHER STUDIES WITH LIME AND BORON ON CRIMSON CLOVER

Lime treatments of 0, 3, and 16 tons per acre were applied without and with B to greenhouse cultures of Vaiden clay, a strongly acid, highly colloidal soil of the Black Belt. Successive crops were grown with liberal applications of P and K fertilizers. Crimson clover was the third successive crop and the results obtained with this crop are shown in Fig. 5. It was found that the application of B not only prevented the lime-induced B deficiency where the soil was excessively limed, but it also increased the yields of the clover on the unlimed and moderately limed soils.

FIG. 5.—Effect of lime and boron on the growth of crimson clover on Vaiden clay. Pots 1 and 4 unlimed; pots 2 and 5 limed to 50% Ca saturation; and pots 3 and 6 limed to 150% Ca saturation. Boron was not applied to soil in pots 1 to 3 but was applied in pots 4 to 6.

In the summer of 1941, an area of Norfolk loamy sand on the Alabama Agricultural Experiment Station Farm was selected for studies with lime and B. Various sources of lime were applied to greenhouse cultures and also to field plots enclosed in metal rims. Boron was applied to certain of these greenhouse cultures and field plots. Crimson clover was planted in the fall and an excellent stand of seedlings was obtained. It was observed early that the seedlings were dying on both the unlimed and limed soils where B was not applied. However, where B was applied, stands were maintained, excellent growth resulted, and the plants were dark green in color. Results of these studies are shown in Figs. 6, 7, and 8 for both greenhouse and field crops.

DISCUSSION

The need for and the value of winter legumes in the Southeast justify every possible effort to establish such crops successfully in the cropping system of the area. The findings reported in this investigation in which crimson clover was shown to be successfully grown in the greenhouse on Coastal Plains soils by the use of supplements of B with the ordinary use of fertilizer and lime may, therefore, have significant practical applications. These results not only show that

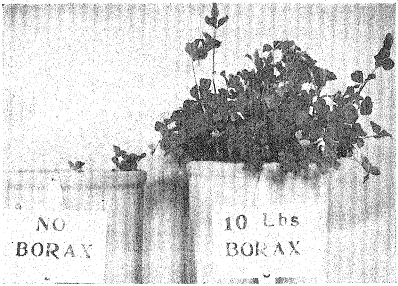


FIG. 6.—Crimson clover on Norfolk loamy sand limed with 2 tons per acre of dolomite lime. No boron added at left and 10 pounds of borax per acre added on right.

the growth of crimson clover was successful in vegetative yields, but also point to the possibility of the crop in the production of home-grown seed. Each of these factors is vitally important in the establishment of a successful winter legume program.

Reports made during earlier attempts to grow crimson clover on the sandy soils of the Coastal Plains area showed that, although satis-

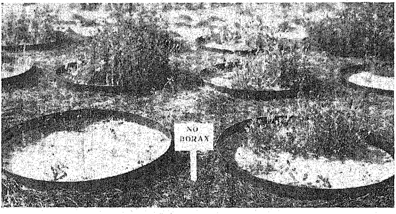


FIG. 7.—Crimson clover on field plot without boron. Note poor stand and small growth.

factory germination of seed was obtained, in many instances the seedlings died at an early stage. Examination of the roots of the seedlings showed darkening of the conducting tissue and retarded development of roots as compared with healthy vigorous roots on seedlings where B was applied. Seedlings that survived on B-deficient soils showed deficiency symptoms typical of those reported earlier by numerous investigators in that dwarfed plants with red foliage developed. Although the seed was inoculated with commercial legume cultures, few or no nodules developed on plants grown on B-deficient soils.

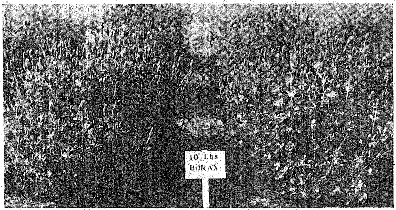


FIG. 8.—Crimson clover on field plot with 10 pounds per acre borax. Note good stand and good growth.

It appears from the results of this investigation that crimson clover requires the addition of small amounts of B for normal growth on some soils. Many of the soils of the Coastal Plains are extremely low in B, and where lime is applied, the need for B additions by leguminous and other crops is increased (9). It is quite probable that some crimson clover failures on soils low in available B content have been due to a deficiency of this essential element. It should be stated that a response to B is obtained on moderately limed soils as well as on excessively limed soils. It is suggested from the results of this investigation that practical application of B might be made for legumes by the use of specially prepared mixtures of phosphate and potash containing supplements of B.

SUMMARY

The response of crimson clover to applications of B in addition to the ordinary use of fertilizer and lime has been investigated on the light sandy soils of the Lower Coastal Plains. The results of this study are summarized below:

1. Crimson clover responded favorably to applications of B on soils where residual fertilizers and lime had caused various degrees of soil acidity. Boron gave favorable response on moderately limed soils as well as on excessively limed soils.

2. Where B was added in concentrations from 0 to 1.5 p.p.m. to soils at various levels of liming, 0.3 p.p.m. B were most effective in development of seed heads and in total plant yields. There was little difference in the plant yields when 0.3 to 0.9 p.p.m. B were added.
3. Several commonly used sources of lime were applied to soils in increasing increments and it was observed that crimson clover made outstanding yields where blast furnace slag was the source of lime. This response probably was due to the B contained in the slag. Later, when B was supplied with other sources of lime, similar favorable response was obtained regardless of the source of lime.
4. Field plots with lime and B treatments similar to those made in the greenhouse also showed favorable effects from B on crimson clover.
5. Results from this investigation indicate that fertilization may need to include small amounts of B for the successful growth of crimson clover on soils of the Lower Coastal Plains and on other soils low in B content.

LITERATURE CITED

1. ALEXANDER, E. D. Crimson clover for fertilizer, feed and soil protection. Ga. Agr. Ext. Service Bul. 452. 1938.
2. ANONYMOUS. Boron and seed production. Nova Scotia Dept. Agr. Ext. News Service. Oct. 14, 1936.
3. BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F. Experiments with legumes in Alabama. Ala. Agr. Exp. Sta. Bul. 232. 1930.
4. DMITRIEV, K. A. Use of boron as a clover manure in seed production. Dokl. Akad. S-Kh. Nauk., 5:35–36. 1937. (Abs. in Soils and Fert., 1:209. 1938.)
5. DUGGAR, J. F. Experiment with crimson clover and hairy vetch. Ala. Agr. Exp. Sta. Bul. 96. 1898.
6. HOLLOWELL, E. A. Crimson clover. U. S. D. A. Leaflet 160. 1938.
7. MCLARTY, H. R., WILCOX, J. C., and WAADBRIDGE, C. G. Yellowing of alfalfa due to boron deficiency. Sci. Agr., 17:515–517. 1937.
8. MOOERS, C. A. Clovers and grasses for hay and pasture. Tenn. Agr. Exp. Sta. Bul. 165. 1938.
9. NAFTEL, J. A. Soil liming investigations: V. The relation of boron deficiency to over-liming injury. Jour. Amer. Soc. Agron., 29:761–771. 1937.
10. ODELIEN, M. Effect of born deficiency and boron application on certain crop plants grown in sphagnam peet with varying calcium content. Meldinger Norges Landbrukshoiskole, 18:54–89. 1938.
11. SOKOLOV, A. V., D'IAKOVA, E. V., and DMITRIEV, K. A. The effect of boron on the seed and hay yields of leguminous plants. Khim. Sotzial, Zemled., 5:57–70. 1937.
12. WILLIS, L. G., and PILAND, J. R. A response of alfalfa to borax. Jour. Amer. Soc. Agron., 30:63–67. 1938.

SOME GENETIC AND MORPHOLOGIC CHARACTERS AFFECTING THE POPPING EXPANSION OF POPCORN[1]

P. J. LYERLY[2]

THERE are few crops which vary more in quality than popcorn. Some of these causes can be remedied by better methods of storage and care in getting the crop from the producer to the consumer. Others can be remedied only by improvement in variety or type.

Popping expansion, or popping volume, measured as units of volume of popped corn obtained from an original unit of shelled corn, is used as the primary criterion of quality. The importance of this measure to the operators of commercial establishments is obvious since their product is sold on the basis of volume rather than weight. A high expansion is also associated with palatability because the lighter and fluffier kernels are usually the more tender.

Considerable progress has been made in the improvement of a few varieties by seed selection. Much greater improvement is now possible, however, by using the modern method of hybridization of inbred lines which has been so successful with field corn. Except for evidence obtained from studies to improve popping expansion by mass selection, little is known of the inheritance of popping quality. It is reasonable to assume that expansion of popcorn is conditioned by certain properties of the endosperm and pericarp and hence the mode of inheritance may be very complex. Any information on the relation between the popping expansion of inbred lines and their hybrids and on the relation of kernel characters and popping expansion should be of value in outlining and conducting a well-planned breeding program for this crop.

MATERIALS AND METHODS

Twenty-nine inbreds classified from previous work as high or low in popping expansion were selected from the varieties Yellow Pearl and Japanese Hulless. The high expansion inbreds ranged from 25.4 to 31.1 volumes and the low expansion inbreds from 15.0 to 23.4 volumes. The name Yellow Pearl, also applied to a distinct variety, is used as a type name in this study for all yellow varieties having pearl type kernels.

In order to determine the relation between popping expansion of inbred lines and their F_1 crosses, 202 crosses were made in 1940 between high and low popping lines within and between the two groups of varieties as shown in Table 1.

Each of the three groups with standards for comparisons were arranged in a randomized block design with five replications. The test plot size was 2×5 hills, thinned to three plants per hill. The inbred material was space-planted in five replicated 30-foot rows, approximately 10 inches between plants.

[1]Part of a thesis submitted at Iowa State College in partial fulfillment of the requirements for the degree of doctor of philosophy. Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper J1022. Project 345. Received for publication June 15, 1942.

[2]Research Assistant.

TABLE 1.—*History of crosses.*

Popping volume of parental lines	Number of crosses
Crosses Between Yellow Pearl Inbred Lines	
High × High	27
High × Low	39
Low × Low	15
Total	81
Crosses Between Japanese Hulless Inbred Lines	
High × High	22
High × Low	41
Low × Low	15
Total	78
Crosses Between Yellow Pearl and Japanese Hulless Inbred Lines	
High × High	18
High × Low	13
Low × Low	12
Total	43

The inbreds and hybrids contained from 13 to 21% moisture when harvested. Approximately 15 ears from each plot were saved for popping tests. These were dried to approximately 10% moisture and the dried ears hung in an open shed until the middle of November at which time they were still considerably below optimum moisture for popping. Approximately 1 pint of the shelled grain from each plot was stored in a high-humidity conditioning room for about 3 weeks. After conditioning, when the Japanese Hulless samples contained approximately 12% and the Yellow Pearl samples approximately 12½% moisture, the samples were placed in moisture proof cans and stored until popped.

The popper used was of the usual electric commercial type. A sample of 100 cc of unpopped, cleaned corn was used for all tests. Ten cc of Mazola corn oil were poured in the popper with each sample. After popping the corn was transferred to a metal cylinder and the expansion read from a graduated plunger. Duplicate popping tests were made on each plot.

To determine the relationship between certain kernel characteristics and popping expansion, the weight in grams per 100 kernels, kernel length, width, thickness, and density were determined on the group of Yellow Pearl crosses. Kernels were taken at random for the length, width, and thickness measurements. Density was determined by volume displacement of a known weight (approximately 14 grams) of corn in a solution of 50% alcohol.

Materials and procedures used in a study of the effect of xenia on popping expansion will be discussed later.

EXPERIMENTAL RESULTS

The data from this investigation will be presented under three major divisions, *viz.*, (a) relation between the popping expansion of single crosses and their parental inbreds, (b) relation between certain kernel characteristics and popping expansion, and (c) effect of xenia on popping expansion.

RELATION BETWEEN POPPING EXPANSION OF SINGLE CROSSES AND THEIR PARENTAL INBREDS

As previously indicated, three groups of single crosses were included in this study, crosses among inbred lines of Yellow Pearl, Japanese Hulless, and intertype crosses between Yellow Pearl and Japanese Hulless. The data from each group are presented separately below.

Crosses between Yellow Pearl inbreds.—The average popping expansions of the 81 Yellow Pearl single crosses are presented in Table 2. There was insufficient seed of three single crosses to include them in the regular yield trial. These were grown in single plots and the popping expansion as determined from these single plots are included in the table. No seed was obtained from three single crosses. The expansion of these combinations was estimated from the average of the parental inbreds in similar crosses. For example, the popping volume of D-26 ×YP-23 was estimated as the mean of the average expansion of D-26 ×high expansion inbreds plus the average expansion of YP-23×low expansion inbreds.

The analysis of variance for popping expansion is presented in Table 3. The mean square within plots is the uncontrolled or sampling variance which may be attributed primarily to variations in popping. The coefficient of variability based on the within plot mean square for this group of crosses, 3.2%, is typical of the two other groups of crosses to be discussed later. The variation attributed to popping may be considered very low particularly since the duplicate samples were popped from several days to a week apart and in some cases by different workers and indicates that two popping tests are sufficient to measure the expansion of a particular plot.

The variety×replication mean square, error b, was significantly higher than the sampling error. This was probably in part due to differences between replications in moisture content of the samples and to differences in yield and seed condition as influenced by soil heterogeneity. The coefficient of variability for popping expansion based on the variety×replication interaction in these experiments ranged from 6.7 for the group of Yellow Pearl crosses to 10.1 for the Japanese Hulless crosses. These coefficients of variability are approximately the same as normally obtained for corn yields.

The experimental hybrids, as previously mentioned, were further divided into three groups based on the expansion of their parental inbreds, high×high, high×low, and low×low. A highly significant difference in popping expansion was obtained between the hybrids within each group and also between the means of each group. The frequency distributions of the high and low parental inbreds and of the single crosses within each group are presented in Table 4. The distributions of the high×high and of the low×low groups of single crosses both extended somewhat beyond their parents. The mean of both groups differed from the mean of their respective parents, however, by less than 1 volume. The high×high single cross with the lowest average volume was higher in expansion than the highest combination of low-popping inbred lines. These results indicate that

TABLE 2.—*Average popping expansion of Yellow Pearl single crosses and parental inbreds grown at Ames, Iowa, in 1941.*

	YP-17	YP-18	YP-19	YP-20	YP-21	YP-22	YP-23	YP-24	D-25	D-26	YP-27	YP-28	YP-29	YP-31	Average, excluding YP-31
YP-17	*28.5*	30.6	30.8	32.1	32.2	31.7	30.1	29.6	24.4	28.3	25.6	26.2	29.0	—	29.2
YP-18	30.6	*29.4*	30.3	30.7	32.5	27.0	29.2	26.7	20.1	22.1*	20.6	27.6	22.7	—	26.7
YP-19	30.8	30.3	*29.2*	30.9	31.4	30.0	29.6	27.1	19.8*	24.4	21.1	23.0	25.9	—	27.0
YP-20	32.1	30.7	30.9	*29.7*	33.3	31.2	28.5	30.0	23.4	27.1	24.4	28.7	28.9	—	29.1
YP-21	32.2	32.5	31.4	33.3	*30.0*	30.0*	30.8	29.8†	24.6	28.6	24.5	26.3	28.6	—	29.4
YP-22	31.7	27.0	30.0	31.2	30.0*	*31.1*	24.1	27.4	19.9	21.6	18.3	23.6	18.6	—	25.3
YP-23	30.1	29.2	29.6	28.5	30.8	24.1	*27.2*‡	27.3	16.9	22.6†	21.0	22.9†	24.6	—	25.6
YP-24	29.6	26.7	27.1	30.0	29.8†	27.4	27.3	*26.0*	13.1	19.2	18.7	19.4	25.1	20.2	24.4
D-25	24.4	20.1	19.8*	23.4	24.6	19.9	16.9	13.1	*18.8*	15.9	10.8	16.2	18.5	13.8	18.6
D-26	28.3	22.1*	24.4	27.1	28.6	21.6	22.6†	19.2	15.9	*21.9*	12.7	24.0	20.1	15.9	22.2
YP-27	25.6	20.6	21.1	24.4	24.5	18.3	21.0	18.7	10.8	12.7	*17.1*	20.6	20.9	15.8	19.9
YP-28	26.2	27.6	23.0	28.7	26.3	23.6	22.9†	19.4	16.2	24.0	20.6	*17.5*	23.5	15.1	23.5
YP-29	29.0	22.7	25.9	28.9	28.6	18.6	24.6	25.1	18.5	20.1	20.9	23.5	*17.6*	21.6	23.9
YP-31	—	—	—	—	—	—	—	20.2	13.8	15.9	15.8	15.1	21.6	*15.8*	—
Average, excluding YP-31	29.2	26.7	27.0	29.1	29.4	25.3	25.6	24.4	18.6	22.2	19.9	23.5	23.9		

*One row plots.
†Estimated.
‡Mean of volumes obtained in 1939 and 1940.

one can be reasonably sure of high expansion hybrids when high expansion inbreds are crossed, and likewise the hybrids of low expansion inbreds will generally be low.

TABLE 3.—*Analysis of variance of popping expansion of 78 Yellow Pearl single crosses and one single cross and two open pollinated varieties as standards for comparison grown at Ames, Iowa, in 1941.*

Source of variation	d/f	M.S.	F
Total	809	—	—
Between plots	404	616.6	228.4†
Varieties	80	3,002.4	1,103.8†
Within groups	77	118.9	43.7†
Checks	2	151.0	55.5†
High × High	25	46.0	16.9†
High × Low	36	152.4	56.0†
Low × Low	14	158.2	58.2†
Between groups	3	4,955.3	1,821.8†
Replications	4	4.9	1.8
Error B	320	2.7	4.2†
Within plots (error A)	405	0.6	—

Group Comparisons*

Groups compared	Group means	Difference	d/f	M.S.	F.
High × High vs. High × Low	29.8–23.4	6.4	1	6,358	2,337†
High × High vs. Low × Low	29.8–17.7	12.1	1	14,006	5,149†
High × Low vs. Low × Low	23.4–17.7	5.7	1	3,446	1,267†

†Highly significant (probability less than .01).
*The group comparisons listed here are certain comparisons which are of interest and have been obtained from the between group sum of squares. This group of comparisons is non-orthogonal and for that reason is not included in the regular analysis above.

The high×low crosses were intermediate and their range included that of both parents. The mean of this group, 23.4 volumes, was about equal to the mean of the high and low inbred parents, 23.6 volumes. The expansions from the high×high and the low×low crosses showed a very good agreement with their parental inbreds, but in the high×low group certain combinations were equal to crosses of high-popping parents and others were no better than those from low-popping parents. These results suggest that some low-popping inbred lines may be of value in crosses with high-popping lines.

Crosses between Japanese Hulless inbred lines.—Unfortunately, the field in which the Japanese Hulless crosses were grown was very non-uniform and poorly drained. The plants on about one-half of the field were stunted by standing water in the early part of the season. Early cultivation was impossible and as a consequence the field became very weedy. An alkali spot caused some additional stunting later in the season. The seed condition and yield on some of the plots therefore was rather poor and these factors probably account for a somewhat greater variability in expansion between the plots in this experiment than for the Yellow Pearl group.

TABLE 4.—*Frequency distributions of popping expansion of Yellow Pearl parental inbred lines and single crosses grown at Ames, Iowa, in 1941.*

	Popping expansion																									No.	Mean
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33		
High inbreds....	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	3	1	1	–	–	8	28.9
Low inbreds....	–	–	–	–	–	–	1	0	3	1	0	0	1	–	–	–	–	–	–	–	–	–	–	–	–	6	18.2
High × High...	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	0	1	4	1	3	9	3	3	1	26	29.8
High × Low....	–	–	–	–	1	0	0	1	0	3	3	3	3	1	3	6	3	2	2	5	1	–	–	–	–	37	23.4
Low × Low....	–	1	0	1	1	0	4	1	0	1	0	3	1	0	1	1	–	–	–	–	–	–	–	–	–	15	17.7

A frequency distribution of the parental inbreds and their hybrids is shown in Table 5. The results from the study of these crosses were not as clear cut and definite as those of the Yellow Pearl type. There was no definite line of demarkation between the three groups of crosses particularly at the high-popping range of the distribution. The single crosses J-7×J-10, a high×low combination, exceeded the highest high×high combination by 1.2 volumes, and the low×low single cross J-10×J-12 was only 1 volume less than the highest high×high combination. The lowest low×low combination was only 0.6 volume lower than the lowest high×low combination.

The popping expansion of all Japanese Hulless single crosses is presented in Table 6. The inbred that gave the highest average performance in single crosses, J-10, was not a high expansion inbred, but the second lowest in popping volume. Apparently the genetic constitution of this inbred is such that the development of the seeds is not normal. This character, however, was not expressed in hybrid combinations. The five highest popping single crosses of the low×low inbreds and the five highest popping crosses of the high×low group involved J-10.

Similarly, one of the high expansion inbreds, J-2, apparently contributed low expansion to many of its hybrids. Certain combinations involving J-2, such as J-2×J-7 for example, were very good; however, in general the crosses involving J-2 were below the average of those from other high-popping lines. It would appear that these two lines are distinctly different from the other inbreds in their respective groups as measured in the popping expansion of their crosses (Table 7).

When the crosses involving J-10 and J-2 are excluded the average of the high×high combinations and the average of the low×low combinations, 24.2 and 16.3, were still considerably below the average of the corresponding high and low parental inbreds, 27.0 and 19. The lower expansion of the hybrids can be explained in two ways. As previously stated, the seed condition from some of the plots was rather poor because of adverse conditions. Secondly, the moisture of the Japanese Hulless crosses when popped was about 12%, slightly below optimum.

Intertype crosses between Yellow Pearl and Japanese Hulless inbred lines.—As in the intratype Japanese Hulless crosses, the combinations involving J-10 were considerably higher in expansion than crosses involving other low-volume inbreds. The high expansion yellow Japanese Hulless inbred YJ-14 acted in a similar way as J-2 in crosses. The four lowest combinations of the high×high group and three lowest combinations of the high×low group involved YJ-14. It should be pointed out, however, that the expansion of YJ-14 (25.6) was lower than that of the other two high expansion Japanese Hulless inbreds, YJ-15 (30.3) and J-1 (27.8) included in this series of crosses.

The means of the three groups of combinations were also below the average of the parental inbreds. There was a much wider range particularly at the lower end of the frequency distribution (Table 8) than was present in the previous experiments. These lower expansions cannot be explained by seed condition and it is doubtful if the

TABLE 5.—*Frequency distribution of popping expansion of Japanese Hulless inbred lines and single crosses grown at Ames, Iowa, in 1941.*

	Popping expansion																							No.	Mean
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
High inbreds	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	3	2	0	1	—	—	7	27.0
Low inbreds	—	—	—	—	—	—	1	0	1	1	0	1	0	0	1	—	—	—	—	—	—	—	—	5	19.1
High × High	—	—	—	—	—	—	—	—	—	—	—	2	1	2	6	7	2	1	—	—	—	—	—	21	23.8
High × High (excluding J–2)	—	—	—	—	—	—	—	—	—	—	—	—	—	1	6	6	2	—	—	—	—	—	—	15	24.2
High × Low	—	—	—	1	0	0	1	1	1	1	4	10	7	5	5	1	3	0	1	—	—	—	—	41	21.2
High × Low (excluding J–2 and J–10)	—	—	—	—	—	—	—	1	1	0	4	9	6	4	3	—	—	—	—	—	—	—	—	28	20.8
Low × Low	—	—	1	1	1	0	2	0	1	2	1	1	2	1	0	1	1	—	—	—	—	—	—	15	18.6
Low × Low (excluding J–10)	—	—	1	1	1	0	2	0	1	2	1	1	—	—	—	—	—	—	—	—	—	—	—	10	16.3

TABLE 6.—*Average popping expansion of Japanese Hulless single crosses and parental inbreds grown at Ames, Iowa, in 1941.*

	J–1	J–2	J–3	J–4	J–5	J–6	J–7	J–8	J–9	J–10	J–11	J–12	YJ–16	Average
J–1	*27.8*	24.5	25.5	24.9	23.9	24.4	25.6	19.6	22.9	25.6	23.1	23.9	20.8	23.7
J–2	24.5	*26.5*	22.6	20.0	20.6	21.9	26.7	18.6	20.7	23.8	15.7	21.1	12.4	20.7
J–3	25.5	22.6	*26.0*	23.9	23.8	24.2	24.9	20.9	21.1	24.3	21.1	22.2	20.6	22.9
J–4	24.9	20.0	23.9	*25.4*	23.3	23.9	24.8	20.6	20.9	23.5	17.8	20.0	21.8	22.1
J–5	23.9	20.6	23.8	23.3	*26.4*	22.4	23.5	19.9	21.0	25.2	19.3	22.0	21.5	22.2
J–6	24.4	21.9	24.2	23.9	22.4	*27.0*	24.0	20.3	22.2	25.2	20.4	22.2	20.5*	22.6
J–7	25.6	26.7	24.9	24.8	23.5	24.0	*29.6*	19.3	21.8	27.9	20.1	23.4	16.1	23.2
J–8	19.6	18.6	20.9	20.6	19.9	20.3	19.3	*18.9*	18.3	22.5	15.7	18.2	15.1	19.1
J–9	22.9	20.7	21.1	20.9	21.0	22.2	21.8	18.3	*20.5*	24.7	12.9	20.4	13.6	20.0
J–10	25.6	23.8	24.3	23.5	25.2	25.2	27.9	22.5	24.7	*17.7*	21.6	25.7	21.2	24.3
J–11	23.1	15.7	21.1	17.8	19.3	20.4	20.1	15.7	12.9	21.6	*15.0*	17.4	11.8	18.1
J–12	23.9	21.1	22.2	20.0	22.0	22.2	23.4	18.2	20.4	25.7	17.4	*23.4*	19.2	21.3
YJ–16	20.8	12.4	20.6	21.8	21.5	20.5*	16.1	15.1	13.6	21.2	11.8	19.2	*19.5*	17.9
Average	23.7	20.7	22.9	22.1	22.2	22.6	23.2	19.1	20.0	24.3	18.1	21.3	17.9	

*Estimated.

moisture content of the seed was below optimum for popping. The lower expansions obtained from these crosses probably were associated in part with their high yield level. The mean yield of these crosses was approximately equal to the Yellow Pearl crosses and considerably above that for the Japanese Hulless combinations.

TABLE 7.—*Group means and significance of differences between group means of Japanese Hulless single crosses including and excluding inbreds J-2 and J-10.*

Groups compared	Group means	Difference	d/f	M.S.	F
High × High vs. High × Low	23.8–21.2	2.6	1	897.5	189.7*
High × High vs. Low × Low	23.8–18.6	5.2	1	2,382.0	503.6*
High × Low vs. Low × Low	21.2–18.6	2.6	1	786.0	166.2*
High × High excluding J-2 vs. High × J-2	24.2–22.7	1.5	1	94.6	20.0*
Low × Low excluding J-10 vs. Low × J-10	16.3–23.1	6.8	1	1,571.8	332.3*
High × Low excluding J-10 vs. High × J-10	20.5–25.1	5.4	1	1,241.8	262.5*
High excluding J-2 × Low vs. Low × J-2	21.7–18.7	3.0	1	450.7	95.3*

*Highly significant.

Previous study by Brunson (1)[3] and data obtained at the Iowa Agricultural Experiment Station indicate that there may be a negative association between popping expansion and yield. The ears of these combinations were intermediate between the two parental types in shape, the kernels tending to be long and flat resembling dent corn kernels. Data to be presented later will show that expansion is negatively correlated with kernels of this shape. In general, however, the agreement between the results from inter and intratype crosses was good. Typical ears of Yellow Pearl, Japanese Hulless, and the intertype crosses are shown in Fig. 1.

These intertype hybrids between Yellow Pearl and Japanese Hulless seem to offer much promise, particularly for home use since these crosses tend to combine the yield of the Yellow Pearl with the tenderness of the Japanese Hulless.

RELATION BETWEEN POPPING EXPANSION AND CERTAIN MORPHOLOGICAL CHARACTERS

The correlation coefficients of popping expansion with kernel weight, length, width, thickness, thickness/width, and density of the Yellow Pearl hybrids previously discussed are presented in Table 9. There appears to be a definite association between kernel size and shape and popping expansion. The smaller, shorter, and narrower kernels tended to give the highest popping expansion. The correlation

[3]Figures in parenthesis refer to "Literature Cited", p. 999.

TABLE 8.—*Frequency distribution of popping expansion of Yellow Pearl and Japanese Hulless inbred lines and intertype crosses grown at Ames, Iowa, in 1941.*

	Popping expansion																										No.	Mean
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
High inbreds	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	1	3	2	1	10	28.8
Low inbreds	–	–	–	–	–	–	–	–	–	1	0	4	1	1	1	1	0	1	–	–	–	–	–	–	–	–	10	19.0
High × High	–	–	–	–	–	–	–	–	–	–	1	0	0	0	1	1	1	2	1	2	1	0	1	4	3	–	18	26.0
High × High (excluding YJ–14)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	0	0	1	4	3	–	12	28.0
High × Low	–	–	–	–	–	–	–	–	–	1	1	0	1	1	1	3	0	4	0	0	1	–	–	–	–	–	13	21.1
High × Low (excluding YJ–14)	–	–	–	–	–	–	–	–	–	–	–	–	–	1	0	3	0	3	0	0	1	–	–	–	–	–	8	22.5
Low × Low	1	0	0	1	0	1	3	0	0	1	0	0	2	0	0	0	0	2	1	–	–	–	–	–	–	–	12	15.8
Low × Low (excluding J–10)	1	0	0	1	0	1	3	0	0	1	0	0	2	–	–	–	–	–	–	–	–	–	–	–	–	–	9	13.1

TABLE 9.—*Correlation coefficients of various morphological characters with popping expansion.*

Character	Correlation with popping expansion
Weight of seeds	−0.44†
Length of seeds	−0.60†
Width of seeds	−0.50†
Thickness of seeds	0.26*
Thickness/width	0.57†
Density of seeds	0.26*

*Significant at the 5% level.
†Significant at the 1% level.

between thickness divided by width, a general measure of the roundness of the kernel, and popping expansion was higher than the correlation between popping expansion and either of the two measurements taken alone. Experience gained through working with a large number of hybrids and inbreds has indicated that the highest volumes are usually attained from samples with medium to small kernels, rounder than average, and with a very vitreous endosperm. Deep, wide, flat kernels resembling dent corn kernels in shape invariably give a low expansion.

These data are in agreement with those reported by Willier and Brunson (5) for weight, length, and width of seeds. Willier and Brunson, however, found a negative correlation between thickness of the kernel and popping expansion, while data in this investigation indicate a positive relationship.

The correlation between density of kernels and expansion, although significant, was too small to be of practical value.

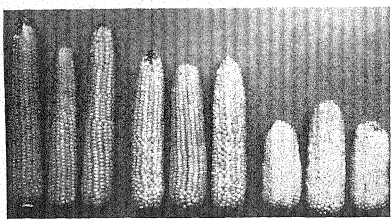


FIG. 1.—Typical ears of Yellow Pearl (left), Yellow Pearl × Japanese Hulless (center), and Japanese Hulless (right) single crosses.

EFFECT OF XENIA ON POPPING EXPANSION

Any immediate marked effect of cross pollination on popping expansion would be of considerable importance in a breeding program where high- and low-popping hybrids or inbred selections are grown side by side and also in commercial production where dent corn may occur beside popcorn. A number of investigators have reported an increase in seed size as a result of crossing unrelated strains of corn. Kiesselbach (3) has reviewed the literature on this subject. The pollen parent is also known to have immediate effect on certain chemical properties of the endosperm such as the carotenoid pigments (2) and precursors of vitamin A (4).

In order to test the effect of xenia on popping expansion a number of cross pollinations were made between high- and low-popping single crosses. Approximately 15 pollinated ears of each cross were obtained. Five or more popping tests were made on each cross depending on the quantity of seed available. The average popping expansion of sibbed seed and crosses made on each maternal parent are shown in Table 10.

The data obtained show a very slight effect of xenia on popping expansion. In general, high-expansion single crosses pollinated with low-expansion types tended to give a lower volume than sibbed seed (average of crosses on five maternal parents 28.7 and 29.2, respectively) and likewise low-popping strains pollinated with high strains tended to give a higher expansion than sibbed seed (average of crosses on four maternal parents 19.4 and 18.4). A number of exceptions were obtained, however. Since some crosses on a maternal parent were made on early-maturing plants and others on late-maturing plants, this factor may have caused some variation between crosses. Such differences as do exist, however, are not large and it may be concluded that the effect of xenia on expansion which would occur in comparative yield trials is not of sufficient magnitude to constitute a serious source of error.

TABLE 10.—*Average popping expansion of single crosses when sib pollinated and when pollinated with high and low volume male parents.*

Maternal parent	Average popping expansion of maternal parent		
	Sib pollinated	Pollinated with	
		Low pop*	High pop*
H-1	28.6	27.1	—
H-2	30.4	30.1	—
H-3	28.0	28.4	—
H-4	29.9	28.7	—
H-5	28.9	29.3	—
L-6	17.8	—	18.5
L-7	17.9	—	20.8
L-8	20.3	—	20.8
L-9	17.3	—	17.4

*Average of 1-4 crosses.

The percentage of seed set may in some cases affect popping expansion. In 1940 in a comparison of sibbed and open-pollinated seed of 14 strains, the sibbed seed in 13 cases gave a higher expansion. This undoubtedly was due to the lower seed set on hand-pollinated ears which resulted in more spherical kernels. The relation between seed shape and expansion has been discussed.

Two high volume single crosses were pollinated with dent, flint, flour, and sweet corn and the popping expansions of the crossed seed are presented in Table 11. The immediate effect of pollen from non-popcorn types was not great, although in seven of eight comparisons the popping volume was slightly decreased.

TABLE 11.—*Average popping expansion of single crosses when sib pollinated and when pollinated with dent, flint, flour, and sweet corn pollen.*

Maternal parent	Average popping expansion of maternal parent				
	Sib pollinated	Pollinated with			
		Dent	Flint	Flour	Sweet
H-1	28.6	25.7	25.8	27.0	27.3
H-3	28.0	27.8	27.5	26.9	28.4
Mean	28.3	26.8	26.7	27.0	27.9

Although the immediate effect of the pollen parent on popping expansion was negligible, care should be taken not to select seed for planting from popcorn grown near dent corn. The highest expansion obtained from 15 F_1 hybrids with dent, flint, flour, and sweet strains in 1940 was 10.9 volumes. Ears harvested from outcrossed plants of this type may seriously reduce the popping expansion of the commercial crop.

SUMMARY

Crosses of popcorn inbreds selected for both high and low popping expansion were studied. The popping expansion of an inbred was found to give a fairly reliable index of its general performance in hybrid combinations. Crosses of high-expansion inbreds tended to give high-expansion hybrid combinations and hybrids involving low-expansion inbreds tended to be low. Crosses of high×low expansion inbreds tended to be intermediate in expansion. The mean of a group of hybrids was found to approach the mean of the parental inbreds.

The weight, length, and width of seeds were found to be negatively correlated with popping expansion, while thickness and density of seeds exhibited slight positive correlations with expansion.

The effect of xenia on popping expansion was found to be slight and not of sufficient magnitude to constitute a serious source of error in comparative yield trials.

LITERATURE CITED

1. BRUNSON, A. M. Popcorn breeding. U. S. D. A. Yearbook, 1937:395-404. 1937.
2. JOHNSON, I. J. and MILLER, E. S. Immediate effect of cross pollination on the carotenoid pigments in the endosperm of maize. Cereal Chem., 26:88-92. 1939.
3. KIESSELBACH, T. A. The immediate effect of gametic relationship and of parental type on the kernel weight of corn. Nebr. Agr. Exp. Sta. Res. Bul. 33. 1926.
4. MANGELSDORF, P. C., and FRAPS, G. S. A direct quantitative relationship between vitamin A in corn and the number of genes for yellow pigmentation. Sci., 73:241-242. 1931.
5. WILLIER, J. C., and BRUNSON, A. M. Factors affecting popping quality in popcorn. Jour. Agr. Res., 35:615-624. 1927.

VIABILITY OF VELVETBEAN, *STIZOLOBIUM* SPP., SEED AS AFFECTED BY DATE OF HARVEST, WEATHERING, STORAGE, AND LODGING[1]

O. L. JUSTICE AND M. D. WHITEHEAD

FOR several years the velvetbean has been an important agricultural crop in many of the southern states and its importance seems to be increasing yearly. Records of germination reports on file in the Alabama State Seed Laboratory show that a high percentage of the samples tested over a period of several years were of poor quality. Some of the samples covered by these reports represented locally grown seed, but a high percentage were samples taken by state inspectors from seed being offered or exposed for sale.

During the spring of 1941, 18 lots of velvetbeans were sampled by state inspectors of which only 8 samples (44.4%) germinated better than 80%, 5 samples (27.8%) between 50 and 80%, and 5 samples (27.8%) less than 50%. Such a high percentage of low-quality seed prompted the authors to begin a study on some of the factors affecting the viability of velvetbeans while harvested and stored under local conditions and conforming with local practices.

Although velvetbeans are usually mature by the middle of November, some farmers do not harvest them until late December or even January. Ordinarily, farmers who postpone the harvest date do not intend to use or sell such velvetbeans for seed but often change their plans and do so. After considerable field experience it was decided that the low viability of many lots of seed placed on the market was probably due to exposure to adverse weather conditions during the latter part of November, December, and January.

METHODS AND MATERIALS

The lots of seed upon which the results reported herein are based were harvested from three fields of Ninety-day velvetbeans, *Stizolobium utile* (Wall.) Piper and Tracy, between September 20, 1941, and February 7, 1942. One field was located near Wetumpka, Ala., on light sandy loam soil. These velvetbeans were growing with corn and the vines were rank, containing large plump pods.

The following lots of seed were harvested from this field on the dates indicated: Lot 1, September 20; lot 2, October 4; lot 3, November 8; lot 4, November 15; lot 5, December 13; and lot 6, December 13. All pods harvested from this field were suspended in the air, except that only pods lying on the ground were included in lot 6.

The second field was located 10 miles west of Montgomery on depleted sandy soil. The vines in this field were stunted, bore flaccid pods, and the foliage died prematurely. The following lots of seed were harvested from this field on the dates indicated: Lot 7, October 25; lot 8, November 29; lot 9, December 9; and lot 10, January 24. All pods harvested from this field were suspended in the air.

The third field was located near Opelika, Ala., and the lots harvested from it

[1]Contribution from the Department of Agriculture and Industry, Alabama State Seed Laboratory, Montgomery, Ala. Received for publication June 30, 1942.

compared favorably with those harvested near Wetumpka. Lot 11, harvested on November 15, and lot 12, harvested on February 7, consisted of pods suspended in the air, while lot 13, harvested on February 7, consisted of pods lying on the ground. The commercial samples were harvested in the autumn of 1940 and stored in a laboratory from April 1941 until tested.

Immediately after harvest each lot of seed, except the small ones, was divided into two portions. One portion was shelled and the seeds classified into the following categories: 1. Green pods—(a) *mature seed*, (b) *immature seed*; 2. Dry pods—(c) *large mature seed without visible mold*, (d) *small mature seed without visible mold*, (e) *mature seed with visible mold around hilum only*, (f) *mature and immature seed with mold on testa other than around hilum*, (g) *small mottled seed free from visible mold but with testa shriveled*, (h) *immature seed free from visible mold*, and (i) *unclassified seed*. A germination test was made on seed from each category immediately after harvest (designated as sublots A). The ungerminated seed (designated as sublots B) and the unhulled seed (designated as sublots C) were stored in paper bags in a laboratory until tested in April. On April 15, 1942, sublots designated as C were shelled and classified, as nearly as possible, into the same categories as sublots A and B. It was not possible to duplicate the classification with the same degree of accuracy as the condition of some of the seed had changed during the interval between harvest and classification. However, any inaccuracy encountered in classification was compensated for, in part, by a corresponding increase or decrease in the percentage of germination. Sublots B and C were tested for germination between April 15 and 29.

The germination tests were made by the modified rag-doll method in which the seed were placed between double thicknesses of moist paper toweling underlain with a heavy sheet of parchment paper. The parchment paper was rolled with the toweling and seed to prevent excessive loss of moisture. Twenty-five seed were used in each test and eight replicate tests were made when the seed supply was adequate. The seed were exposed to a temperature of 20°C for 16 hours and 30°C for 8 hours each day. In the 14-day germination period, the sprouts and dead seed were removed every third day except that the second count was made on the fifth day. The reason for removing the sprouts and dead seed at such close intervals was to reduce the spread of mold from contaminated to sound seed.

RESULTS AND DISCUSSION

The results of the tests expressed in average percentages of germination and hard seed are shown in Tables 1, 2, 3, and 4. The percentage which any classification constitutes of its sublot is based on the number of seed rather than weight. The germination value, or total percentage of live seed, of each classification was determined by multiplying the percentage of viable seed (percentage germination plus hard seed) by the percentage of seed in the classification and dividing by 100. The germination value of any sublot was determined by adding the germination values of the various classifications therein. Because the condition of the seed changed as they grew older, either in the field or laboratory, and because of the error in personal judgment, it was not possible to place all seed in their correct categories. For this reason, the essential comparisons between lots and sublots must be based upon the germination values of the entire sublots rather than upon their component parts.

TABLE 1.—*Germination data on seed harvested from the Wetumpka Field.**

Lot No.	Pods green, seed mature, mottled				Pods green, seed immature				Pods dry, seed mature, free from mold				Pods dry, seed mature, mold around hilum				Unclassified seed				Total % live seed
	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	
Sept. 20, 1941																					
1A	150	87.3	0.0	75.8	25	60.0	0.0	24.2													80.7
1B	75	45.3	48.0		50	46.0	32.0														89.5
Oct. 4, 1941																					
2A	150	82.0	0.0	41.4					150	99.3	0.0	51.7									85.2
2B	175	74.3	16.5						100	80.0	18.0						43	28.0	4.7	6.9	90.5
Nov. 8, 1941																					
3A	75	81.3	0.0	19.9	75	37.1	0.0	20.6	200	98.5	0.0	59.5									82.4
3B	75	73.3	12.0		75	40.0	16.6		200	89.0	11.0										88.2
3C	125	59.2	35.3	16.7					200	92.5	6.5	82.7									97.9
Nov. 15, 1941																					
4A									200	99.0	0.0	100.0									99.0
4B									200	95.5	3.0										98.5
4C									200	95.5	0.5	98.7					10	30.0	0.0	1.3	95.1

									Dec. 13, 1941												
5A									250	92.4	0.0	99.0					10	60.0	0.0	1.0	92.7
5B									225	79.1	17.7										95.8
5C									200	82.0	11.0	100.0									93.0
									Dec. 13, 1941												
6A									225	84.8	0.0	86.7	75	30.0	0.0	12.1					77.1
6B									200	89.0	1.5		50	18.0	2.0		12	41.7	16.6	1.2	81.6
6C									200	77.5	7.5	91.7	50	28.0	0.0	7.7	3	33.0	33.0	0.6	80.4
									Oct. 25, 1941												
7 A†	200	73.5	0.0	40.7	125	7.2	0.0	28.5													
7B	175	78.3	17.7		125	64.0	4.8														
7C	225	70.2	25.7	23.0	75	18.7	1.2	1.9													

*When harvested, all pods were suspended in air except lot 6.
†Lot 7 was harvested from the Montgomery field, but the seed from green pods are listed here for convenience. (See Table 2.)

TABLE 2.—*Germination data on seed harvested from the Montgomery Field.**

Lot No.	Pods dry, seed mature, free from mold				Pods dry, seed mature, mold around hilum				Pods dry, seed immature to mature, mold on testa				Pods dry, testa wrinkled, free from mold				Pods dry, seed immature, free from mold				Total % live seed
	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this lcass	
									Oct. 25, 1941												
7A†	100	98.0	0.0	30.8																	62.0
7B	200	61.5	34.5																		88.1
7C	200	61.0	34.0	65.4									25	64.0	12.0	9.7					91.8
									Nov. 29, 1941												
8A	300	87.0	0.0	81.8					25	20.0	0.0	5.4	50	70.0	0.0	8.9	25	20.0	0.0	3.9	79.2
8B	200	70.0	18.0						25	0.0	0.0		25	52.0	12.0		25	0.0	0.0		77.7
8C	200	78.0	15.0	76.0					50	14.0	0.0	4.9	100	58.0	17.0	13.0	50	10.0	2.0	6.1	81.8
									Dec. 9, 1941												
9A	250	93.2	2.0	77.0					25	12.0	0.0	3.8	50	76.0	2.0	16.2	25	20.0	0.0	3.0	87.0
9B	250	54.4	42.4						25	20.0	0.0		100	43.0	31.0		25	0.0	0.0		87.3
9C	200	60.0	34.0	65.4					50	12.0	0.0	9.3	100	53.0	28.0	21.0	25	12.0	0.0	4.3	80.1
									Jan. 24, 1942												
10A	200	27.5	15.0	40.6	100	7.0	7.0	17.2	200	0.5	0.0	37.8					25	16.0	0.0	4.4	20.6
10B	200	12.5	21.5		100	1.0	11.0		200	0.5	0.5						25	4.0	0.0		16.4
10C	200	16.5	13.5	54.7	100	4.0	8.0	8.2	200	0.5	0.0	32.5					50	6.0	2.0	4.6	18.0

*All pods were suspended in air when harvested.
†See Table 1 for results of seed taken from green pods in lot 7.

TABLE 3.—*Germination results on seed harvested from the Opelika field.**

Date harvested	Lot No.	Pods, dry, seed mature, free from mold				Pods dry, seed mature, mold around hilum				Pods dry, seed immature to mature, mold on testa				Total % live seed
		No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	No. seeds germinated	Germination, %	Hard seed, %	% of lot in this class	
Nov. 15, 1941	11A	400	89.0	1.5	100.0									92.5
	11B	200	85.5	7.0										90.5
Feb. 7, 1942	12A	200	51.5	14.5	88.9	25	20.0	24.0	10.9	25	0.0	0.0	3.1	63.5
	12B	175	61.1	6.8		25	40.0	8.0						65.6
Feb. 7, 1942	13A	200	25.0	13.0	61.5	25	12.0	32.0	7.8	100	0.0	1.0	30.7	27.8
	13B	50	20.0	18.0		25	12.0	20.0		25	0.0	0.0		26.3

*Pods of lots 11 and 12 suspended in the air; lot 13 lying on ground.

Although it is not shown in Tables 1, 2, and 3, the mature seed taken from dry pods were separated into two groups on the basis of size, and germinated. Since there was no appreciable difference between the germination percentages of small and large seed, the results of both groups were combined into a single classification.

TABLE 4.—*Effect of storage for 1 year under air-dry laboratory conditions on the viability of commercial samples of velvetbeans.*

Laboratory No.	Tested Apr. 25–May 9, 1941		Tested Jan. 7–21, 1942		Tested Apr. 25–May 9, 1942	
	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %
19062	90.75	1	84.5	5.0	71.5	8.5
19217	90.0	0	76.0	7.5	79.0	8.0
19251	90.0	0	78.5	11.5	72.5	9.0
19262	72.0	1	55.5	7.5	50.0	12.0
0–5603	72.0	0	44.5	0.5	41.5	0.5

A careful study of Tables 1, 2, and 3 shows that there were no significant differences when the tolerance values for germination adopted by the Association of Official Seed Analysts are applied between the sublots within any lot, except in three cases. All of these differences were found in sublots containing green or immature pods and seed which were tested immediately after harvest, even though a high percentage of these seeds showed the mottled markings of mature seed. The underlying reasons for these differences are (a) difficulty in classifying and blending immature seed and pods, and (b) low germination of immature seed tested immediately after harvest. For example, the total live seed content of seed harvested on October 25 (lot 7) was 62% when tested in October and 89.9% when tested in April. Of the seed in this lot taken from green pods 46.77% germinated with no hard seed when tested in October; when tested in April 72.66% of the seed germinated with 12.0% hard seed. In this particular lot, 15.8% of the seed tested immediately after harvest were considered as weak sprouts and not germinated. Seed stored during the winter, either shelled or in the pod, retained their viability equally well.

Further observations of Tables 1, 2, and 3 show that the germinating value of seed harvested from the Wetumpka and Opelika fields were not significantly different. However, the value of the seed harvested from the Montgomery field differs enough from those harvested from the other two fields that the differences must be considered in making comparisons. If only the seed taken from dry, mature pods which were suspended in the air and harvested between October 4 and December 12 are considered and if these seed should be fairly uniform except for the differences existing between the three fields, the following percentages of live seed will be found: Wetumpka field, 97.2%; Montgomery field, 86.7%; and Opelika field, 91.5%. Thus,

the seed from the Wetumpka field germinated 10.5% higher than those harvested from the Montgomery field.

Seed taken from pods suspended in the air depreciated little or none in viability when left in the field until the middle of December. The seed harvested from scandent vines in the Wetumpka field gradually increased from 85.1% for seed harvested on September 20 to 93.6% for those harvested on December 13. Seed harvested on December 9 from scandent vines on the Montgomery field had a live seed content as good as lots harvested under similar conditions on previous dates. In fact, the live seed content of seed harvested on December 9 was 84.8% compared with 79.6% live seed content for seed harvested on November 29. This variation is well within an accepted tolerance of variation between homogenous samples, but it is not clear why the advantage is in favor of the seed harvested on the later date. When the results of lot 9 are compared with lot 10 and lot 11 with lot 12, it will be seen that the viability of seed on scandent vines depreciated in viability rapidly after the middle of December. Lot 9, harvested from the Montgomery field on December 9, had a live seed content of 84.8%, while seed harvested under similar conditions on January 24 had a live seed content of 18.3%. There were 47 days between the dates of harvest of lots 9 and 10 and 66.3% difference in the germination values. Apparently, this difference was due to the fact that 59% of the seed in lot 10 contained visible mold, while only 6.5% of the seed in lot 9 contained visible mold. Lot 11, harvested from scandent vines on the Opelika field on November 15, contained a live seed content of 91.5%, whereas seed harvested under similar conditions on February 7 had a live pure seed content of only 64.5%. Thus, it is seen that velvetbean seed harvested from scandent vines after December 15 have little value.

On December 13 seed were harvested from the Wetumpka field and the pods from lodged vines were segregated from those taken from scandent vines. Seed from scandent vines had a live seed content of 93.8% compared with a live seed content of 79.7% obtained from seed taken from pods lying on the ground. Similarly, seeds of lots 12 and 13 were harvested from scandent and lodged vines on the Opelika field on February 7. The seed from scandent vines had a live seed content of 64.5%, while those from lodged vines had a live seed content of only 26.9%. Because seed harvested from lodged vines had little planting value and because severe lodging was observed in early December, the evidence indicates that velvetbean seed should be harvested in November.

The results obtained from tests made on five commercial samples are shown in Table 4. These seed had been stored under laboratory conditions from the time they were received in April 1941 until tested in April 1942. The three samples, which germinated 90% in the spring of 1941, suffered little loss, if any, in viability when stored under laboratory conditions for 1 year. One of the two samples, which germinated 72%, lost only 10% in viability, while the other sample lost approximately 30% in viability during the storage period.

No work was done to determine the reason for loss of vitality of lodged seed. However, observations revealed that nonviable seed

were destroyed during the germination test period by fungi and bacteria. Two molds, *Rhizopus nigricans* and *Fusarium* sp.,[3] were isolated from germinating seed. Some of the seed decayed during the test period but did not show evidence of mold infestation. An unidentified bacterium was isolated from one of these seed. It appears that the loss of viability in lodged seed is due to the growth of mold and bacteria. The moisture content of lodged seed is apparently increased so as to make the seed a favorable growth medium for these organisms. This is verified by the fact that high percentages of the lodged seed contained visible mold, while seed from scandent vines contained low percentages of these organisms.

It was also observed that some lodged seed had begun germination at the time of harvest. After being brought to atmospheric dryness, these seed failed to continue germination. Many of the lodged seed had absorbed moisture and expanded, but the radicles had not broken the testa.

Finally, the loss of certain essential cell substances from the lodged seed by leaching is not to be disregarded, unless experimental evidence is presented contradicting such an hypothesis. This possibility is strengthened by the fact that there was 14.12 inches precipitation in the Montgomery, Ala., area between December 1 and February 1. Specific climatological data can be obtained by referring to Emigh.[4] Eyster[5] and others have reported on the loss of vitality of bean seed (*Phaseolus*) which had been soaked in water. Eyster found that much of the resulting loss in viability of seed soaked for 1 day was due to the action of bacteria, but adds that the deleterious effects were due, in part, to the leaching out of proteins, enzymes, and growth-promoting substances.

SUMMARY

Velvetbean seed harvested from three fields in central Alabama between September 20, 1941, and February 7, 1942, were classified on the basis of maturity of pods and seed, the presence or absence of visible mold on the testa, and the shriveled condition of the testa, and were tested for germination immediately after harvest and in the following April.

It was found that a higher percentage of active germination could be obtained from mature or nearly mature seed taken from green pods when tested immediately after harvest than when tested in April, but the total percentage of viable seed was greater when tested on the latter date. Highest germination results were obtained from seed

[3]The identifications were made by C. L. Lefebvre, Pathologist, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

[4]EMIGH, E. D. Climatological data. U. S. Dept. of Commerce, Weather Bureau. Alabama section. Montgomery, Ala. Vol. 47, Nos. 9–12, 1941; Vol. 48, Nos. 1–2, 1942.

[5]EYSTER, H. CLYDE. The cause of decreased germination of bean seeds soaked in water. Amer. Jour. Bot., 27:652–659. 1940.

———. Rules and recommendations for seed testing. Proc. Assoc. Off. Seed Anal. North Amer., 1937:61–84. 1937.

———. Rules and regulations under the Federal Seed Act. U. S. D. A. Service and Regulatory Announcement No. 156. 1940.

harvested during November, but seed harvested in early December showed little or no loss in viability provided seed lying on the ground were not included.

Seed harvested from one field in January and another in February showed a loss of viability amounting to 66.3% and 27.0% when compared with results from seed harvested in December and November, respectively. The viability of seed harvested from lodged vines in December and again in February was 14.3% and 37.4% less, respectively, than the viability of seed harvested from vines supported by cornstalks.

It is concluded that velvetbean seed should be harvested in November or early December in central Alabama. Seed or pods harvested before this time are likely to have a high moisture content and thus become damaged through respiration and heating during storage. If the harvest date is postponed until December or later, many of the vines are likely to become lodged with a resulting loss in the value of the seed.

Hulled and unhulled seed stored under laboratory conditions from the date of harvest until April showed no consistant differences in the germination values when tested at the end of the storage period. Samples from five commercial lots of seed stored in the laboratory for 1 year depreciated very little in germination value.

THE BENEFICIAL EFFECT OF PRELIMING UPON PO_4 UPTAKE FROM INCORPORATIONS OF MONOCALCIUM PHOSPHATE[1]

W. H. MacIntire and B. W. Hatcher[2]

In previous consideration of the joint use of superphosphate and liming materials the transitions that occur in mixtures of superphosphate with limestone and with dolomite outside the soil (2, 3, 5, 6, 7)[3] have been integrated with the changes that water-soluble monocalcium phosphate undergo in prelimed soils (1, 4). It is obvious that some dicalcium phosphate is formed when that phosphate is incorporated with a prelimed soil. In contrast, such an addition to a soil of depleted alkaline earth content involves undesirable reactions with the amphoteric components of the soil colloids and resultant fixation of PO_4. The extent of the formation of the dibasic phosphate is governed by rate, type, and particle size of the liming material and by the thoroughness with which it and the soluble phosphate are disseminated throughout the soil. It is not to be expected, however, that ideal conditions as to uniform distribution of a relatively light incorporation of superphosphate and a heavier incorporation of limestone are to be attained in practice.

The results given in the present paper were obtained by a plant-ash study to determine the effect of preliming at rational rates upon the uptake of PO_4 by rye seedlings from subsequent incorporations of water-soluble calcium phosphate, the principal phosphatic component of superphosphate. The values for additive phosphate and the analytical results are expressed by the conventional symbol, "P_2O_5".

EXPERIMENTAL PROCEDURE

Precipitated calcium carbonate was used for the limings and the stipulated rates are in terms of pounds of $CaCO_3$ per 2,000,000 pounds of air-dry soil. The uptake of P_2O_5 was measured by the Neubauer technic described by Thornton (8) and with the following technic as to preparatory treatments: A 450-gram charge of 2-mm sifted acidic soil was used to supply four 100-gram cultures and a 50-gram surplus for chemical tests. Two charges received dry preparatory incorporations of precipitated $CaCO_3$ and then were moistened and aged 2 weeks. Initial pH value was used as the guide for the liming rate required to induce neutrality. An incorporation of 25 mgms of P_2O_5, as $CaH_4(PO_4)_2.H_2O$ then was made with each unlimed and with each limed culture of 100 grams of soil, diluted with 50 grams of quartz. Duplicate cultures then were seeded with rye and kept at 20°C for 16 days, with a maintained relative humidity of 50%.

The phosphate incorporation corresponded to a P_2O_5 rate of 500 pounds, to a monocalcium phosphate rate of 887 pounds, and to a 16% superphosphate rate of 3,125 pounds per 2,000,000 pounds of soil. The transition of such an incorporation to dicalcium phosphate would require 352 pounds of $CaCO_3$. Upon the

[1]A cooperative study by the University of Tennessee Agricultural Experiment Station, Department of Chemistry, and the Tennessee Valley Authority, Department of Agricultural Relations. Received for publication June 30, 1942.

[2]Head of Department and Scientific Aide, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 1016.

assumption that all of the incorporated acidic phosphate reacted *exclusively* with either the incorporated $CaCO_3$ or the calcic silicates derived from it to form dicalcium phosphate, the capacity of every liming treatment to correct mineral soil acidity therefore was diminished by 352 pounds of $CaCO_3$-equivalence.

The liming rates, initial and altered pH values, and P_2O_5 recoveries from limed and unlimed soils are given in Tables 1 and 2. The pH values resultant from the prelimings constitute the basis for the classification of the soils into the two groups.

EFFECT OF PRELIMING UPON PO_4 UPTAKE

SOILS IN FINAL pH RANGE OF 6 TO 7

The 10 soils that were not brought to a pH of 7 by the aged incorporations of $CaCO_3$ are grouped in Table 1. With one exception, the Sequoia subsoil, final pH values were in the 6.1 to 6.9 range.

TABLE 1.—*The ameliorative effect of preliming in decreasing the fixation of incorporations of water-soluble calcium phosphate, as measured by PO_4 uptake in Neubauer cultures of 10 soils brought to a pH range of 6 to 7.**

Soil type	Phase	Incorporated $CaCO_3$, lbs. per acre†	pH, initial and altered, respectively‡	P_2O_5 Uptake as mgms per 100 grams of soil: Soil only	P_2O_5 Uptake as mgms per 100 grams of soil: Soil + phosphate	P_2O_5 Recovery: Actual, mgms	P_2O_5 Recovery: Percentage of addition
Montevallo silt loam	Normal	None	5.0	2.0	12.9	10.9	43.6
	Normal	3,000	6.6	1.6	16.3	14.7	58.8
Cumberland silt loam	Normal	None	6.1	4.7	13.4	8.7	34.8
	Normal	1,000	6.5	5.4	15.5	10.1	40.4
Telladego silt loam	Normal	None	5.0	2.1	7.8	5.7	22.8
	Normal	3,000	6.2	1.4	9.1	7.7	30.8
Decatur silt loam	Normal	None	5.6	1.2	9.1	7.9	31.6
	Normal	3,000	6.7	1.6	11.7	10.1	40.4
Dewey silt loam	Normal	None	5.6	1.3	10.0	8.7	34.8
	Normal	3,000	6.9	0.6	11.7	11.1	44.4
Cookesville silt loam	Normal	None	5.7	0.8	11.3	10.5	42.0
	Normal	2,000	6.7	1.4	14.3	12.9	51.6
Tellico fine sandy loam	Normal	None	5.8	0.9	7.7	6.8	27.2
	Normal	3,000	6.6	2.1	9.9	7.8	31.2
Savannah fine sandy loam	Eroded	None	4.8	0.6	5.8	5.2	20.8
	Eroded	4,000	6.9	0.9	9.3	8.4	33.6
Wolftever silt loam	Normal	None	5.2	3.2	10.7	7.5	30.0
	Normal	4,000	6.7	3.7	15.3	11.6	46.4
Sequoia silt§	Subsoil	None	4.9	1.8	3.6	1.8	7.2
	Subsoil	6,000	5.8	0.4	4.7	4.3	13.2

*A supply of 25 mgms of P_2O_5 per 100 grams of soil is equivalent to a rate of 500 pounds of P_2O_5 per 2,000,000 pounds of soil.
†Basis of 2,000,000 pounds of soil.
‡Determined at end of curing period of 2 weeks and immediately before seeding.
§Sole subsoil and single exception to the induced pH minimum of 6.

In every case the preliming caused an enhancement in PO_4 uptake, and the differences are well beyond tolerance for analytical error. The mean of the recoveries from the incorporations of water-soluble calcium phosphate with the first nine unlimed soils of Table 1 was 31.9%, in contrast with the 76% recovery obtained from the quartz-culture control in which equilibria conditions developed without vitiation by the PO_4-fixation that occurred in unlimed soil. The 31.9% mean recovery of the phosphate incorporation indicates a fixation of P_2O_5 at the per acre rate of 340.5 pounds, or 68.1% of the experimental incorporation. The mean of the P_2O_5 recoveries from the same nine soils that had been limed before phosphating was 41.9% of the phosphate incorporation, with a reciprocal fixation of 58.1%.

The subsoil listed last in Table 1 was from the Sequoia silt loam of Table 2 and received $CaCO_3$ at the 6,000-pound rate. This was the maximum stipulated for the soils of Table 1 and six times that prescribed for the normal Sequoia silt loam. Even so, the limed subsoil did not attain a pH of 6, whereas the lightly limed silt loam was brought to a pH of 7.2. In spite of the preparatory 6,000-pound $CaCO_3$ incorporation, however, the PO_4-fixation by the subsoil far exceeded the fixation indicated for any of the acidic soils of either Table 1 or Table 2. The P_2O_5 recovery of only 7.2% and the indicated fixation of 92.8% were altered only to a recovery of 13.2% and a fixation of 86.8% as a consequence of preliming. In contrast, the respective recoveries of P_2O_5 from the Sequoia silt loam before and after liming were 41.2% and 48.4%.

SOILS OF pH OF 7 OR BEYOND

This pH range was taken for the grouping of Table 2, which shows the extent to which the reaction of each of these 25 soils had been altered as a result of the liming and aging that preceded the phosphating. The Sequoia silt loam was brought to a pH of 7.2 by a rate of liming only one-sixth of that used for the Sequoia subsoil, the pH of which was changed only from 4.9 to 5.8 by the 6,000-pound incorporation of $CaCO_3$. Nevertheless, the P_2O_5 recovery from the lightly limed Sequoia silt loam was six times the recovery from the more heavily limed Sequoia subsoil.

By exclusion of both the Sequoia silt loam and its subsoil, the mean $CaCO_3$ equivalence of the liming treatments of Table 2 was 4,021 pounds as against 2,888 pounds for the soils of Table 1. The mean of the recoveries from the other 24 unlimed soils of Table 2 was 30.7%, corresponding to a mean fixation of 69.3%, whereas the limed soils showed a mean recovery of 45.7% and a mean fixation of 54.3%. When the P_2O_5 recoveries from the 24 limed soils of Table 2 are compared with recoveries from the first 9 soils of Table 1, it is apparent that the 45.7% mean recovery from the more alkaline soils of Table 2 is only 3.8% above that of 41.9% recovery from less heavily limed and still mildly acidic soils. This recovery is somewhat more than half of the recovery of 76% which was obtained from corresponding incorporations of water-soluble monocalcium phosphate with a quartz medium, in which case the factor of PO_4-fixation was eliminated. Although increases in uptake occur with progression in charges

of additive P_2O_5—for example, the range of 12.5, 25.0, and 37.5

TABLE 2.—*The ameliorative effect of preliming in decreasing the fixation of incorporations of water-soluble calcium phosphate as measured by PO_4 uptake in Neubauer cultures of 25 soils brought to pH of 7 or above.**

Soil type	Phase	Incorporated $CaCO_3$, lbs. per acre†	pH, initial and altered, respectively‡	P_2O_5 Uptake as mgms per 100 grams of soil: Soil only	P_2O_5 Uptake as mgms per 100 grams of soil: Soil + phosphate	P_2O_5 Recovery: Actual, mgms	P_2O_5 Recovery: Per cent of addition
Sequoia silt loam	Normal	None	6.5	0.3	10.6	10.3	41.2
	Normal	1,000	7.2	1.1	13.2	12.1	48.4
Hagerstown silt loam	Normal	None	5.7	1.4	11.2	9.8	39.2
	Normal	4,000	7.6	1.2	13.0	11.8	47.2
Dickson silt loam	Normal	None	5.1	0.7	9.7	9.0	36.0
	Normal	4,000	7.4	1.2	13.3	12.1	48.4
Hartsells fine sandy loam	Normal	None	4.7	0.7	5.6	4.9	19.6
	Normal	6,000	7.3	0.5	10.1	9.6	38.4
Decatur silt loam	Subsoil	None	5.1	0.8	3.6	2.8	11.2
	Subsoil	5,000	7.1	0.8	7.7	6.9	27.6
Dewey silt loam	Subsoil	None	4.9	1.0	8.4	7.4	29.6
	Subsoil	5,000	7.3	0.9	10.0	9.1	36.4
Fullerton silt loam	Normal	None	5.2	1.2	11.0	9.8	39.2
	Normal	3,000	7.1	1.1	11.9	10.8	43.2
Clarksville silt loam	Normal	None	5.3	1.8	12.9	11.1	44.4
	Normal	3,000	7.0	1.6	15.0	13.4	53.6
Paden silt loam	Normal	None	5.7	1.6	10.4	8.8	35.2
	Normal	4,000	7.7	0.9	14.0	13.1	52.4
Paden silt loam	Eroded	None	5.0	1.8	8.9	7.1	28.4
	Eroded	6,000	7.3	1.2	11.8	10.6	42.4
Dulac silt loam	Normal	None	5.4	1.8	12.1	10.3	41.2
	Normal	4,000	7.8	1.0	13.4	12.4	49.6
Dulac silt loam	Eroded	None	5.1	1.3	6.3	5.0	20.0
	Eroded	4,000	7.0	0.7	9.9	9.2	36.8
Savannah fine sandy loam	Normal	None	5.6	2.6	10.5	7.9	31.6
	Normal	3,000	7.8	2.9	15.7	12.8	51.2
Lexington silt loam	Normal	None	5.2	1.1	11.3	10.2	40.8
	Normal	4,000	7.6	0.7	13.8	13.1	52.4
Lexington silt loam	Subsoil	None	4.9	1.2	7.3	6.1	24.4
	Subsoil	5,000	7.4	1.2	13.0	11.8	47.2
Etowah silt loam	Normal	None	6.1	1.3	12.3	11.0	44.0
	Normal	1,500	7.1	1.5	16.0	14.5	58.0
Etowah silt loam	Eroded	None	5.2	0.7	7.4	6.7	26.8
	Eroded	3,000	7.1	1.2	11.5	10.3	41.2
Freeland silt loam	Normal	None	5.2	0.9	7.7	6.8	27.2
	Normal	4,000	7.5	0.5	13.1	12.6	50.4
Freeland silt loam	Subsoil	None	5.1	0.5	4.5	4.0	16.0
	Subsoil	4,000	7.3	1.1	10.1	9.0	36.0

*A supply of 25 mgms of P_2O_5 per 100 grams of soil is equivalent to a rate of 500 pounds of P_2O_5 per 2,000,000 pounds of soil.
†Basis of 2,000,000 pounds of soil.
‡Determined at end of curing period of 2 weeks and immediately before seeding.

TABLE 2.—*Concluded.*

Soil type	Phase	Incorporated $CaCO_3$, lbs. per acre†	pH, initial and altered, respectively‡	P_2O_5 Uptake as mgms per 100 grams of soil: Soil only	P_2O_5 Uptake as mgms per 100 grams of soil: Soil + phosphate	P_2O_5 Recovery: Actual, mgms	P_2O_5 Recovery: Per cent of addition
Providence silt loam	Normal	None	5.2	0.4	11.1	10.7	42.8
	Normal	4,000	7.8	1.0	15.3	14.3	57.2
Providence silt loam	Subsoil	None	5.0	0.4	6.4	6.0	24.0
	Subsoil	4,000	7.3	0.3	11.8	11.5	46.0
Luverne sandy loam	Normal	None	5.8	0.0	8.8	8.8	35.2
	Normal	3,000	7.9	1.2	13.9	12.7	50.8
Luverne sandy loam	Subsoil	None	4.9	0.2	5.5	5.3	21.2
	Subsoil	5,000	7.3	0.3	9.7	9.4	37.6
Ruston sandy loam	Normal	None	5.6	0.2	8.4	8.2	32.8
	Normal	3,000	7.7	1.0	14.1	13.1	52.4
Ruston sandy loam	Subsoil	None	4.7	−0.2	6.3	6.3	25.2
	Subsoil	5,000	7.7	0.2	10.2	10.0	40.0

*A supply of 25 mgms of P_2O_5 per 100 grams of soil is equivalent to a rate of 500 pounds of P_2O_5 per 2,000,000 pounds of soil.
†Basis of 2,000,000 pounds of soil.
‡Determined at end of curing period of 2 weeks and immediately before seeding.

mgm—equilibria conditions are such that complete recovery is not attained by a single Neubauer culture.

RELATIVE RECOVERIES FROM SOILS AND SUBSOILS

In Tables 1 and 2, "eroded phase" connotes a plough-depth mixture of soil and subsoil, whereas "subsoil" connotes a sampling of subsoil after the removal of the normal soil.

The mean of the $CaCO_3$ rates for the normal-phase soils of Table 1 was 2,750 pounds. The mean of the P_2O_5 recoveries from the soils limed at that rate was 43% as against a mean of 33.3% for the unlimed soils. The mean of the $CaCO_3$-equivalent liming rates for the surface soils of Table 2 was 3,433 pounds. The mean of the P_2O_5 recoveries from the limed surface soils of Table 2 was 50.2%, whereas the corresponding mean for those unlimed was 36.7%.

The grand average of liming rates was 3,197 pounds for the normal soils and 4,666 pounds for the subsoils. The resultant P_2O_5 recoveries were 47.7% and 36.5% for the prelimed soils and subsoils, respectively, in comparison with respective recoveries of 36.5% and 21.2% for all unlimed soils and subsoils.

GENERAL DISCUSSION

The results given in Tables 1 and 2 indicate that the preliming (a) decreased substantially the potential capacity of the soils to effect PO_4-fixation, and (b) promoted the formation and persistence of

dicalcium phosphate resultant from reaction between the water-soluble monocalcium phosphate and any residues of the corrective carbonate, or its Ca-complex derivatives formed during the preparatory aging. Even an intensive experimental in-working of the solid carbonate in an amount requisite for complete reaction and replacement of the hydrogen ion of the acidic complexes will fail to effect immediately a complete elimination of inherent acidity. Hence, a fraction of the PO_4 of the incorporated water-soluble phosphate of calcium undoubtedly undergoes fixation by the iron and aluminum of the soil complexes and thereby escapes conversion to $CaHPO_4$. Such fixation, however, is probably only a fraction of that which occurs in the unlimed soil.

It has been demonstrated that the transition of the dicalcium phosphate to the tricalcium compound occurs very slowly in both mixtures and suspensions of the dibasic phosphate and calcium carbonate, even when a substantial excess of $CaCO_3$ is present (5, 6). Dicalcium phosphate continues for protracted periods also in its mixtures with calcium silicates (4). Moreover, the factor of the ultimate formation of calcium fluorphosphate (2, 3) is eliminated by the use of the reagent monocalcium phosphate in lieu of fluoride-bearing superphosphate. Because of the relatively short period of growth, the greater uptake of PO_4 from the prelimed soils of the Neubauer cultures is construed as evident diminution in capacities to effect PO_4-fixation coincident with the conversion of the larger fraction of the added monocalcium salt to the dicalcium phosphate. Although this phosphate is sparingly soluble in water, it is readily soluble in carbonated water, and therefore readily "available".

It might be contended, however, that the limings had caused transition of the dicalcium phosphate to tricalcium phosphate and that the enhancement in PO_4-uptake registered the availability of the PO_4 ion in the tertiary form in contrast with the meager solubility of the same ion after its fixation by colloidal soil complexes. Besides being a sluggish transition, however, the formation of the tertiary phosphate requires an inducive alkalinity beyond that indicated for the soils of Table 1, and also for most of those of Table 2. Related findings indicated that no appreciable development of tricalcium phosphate would have occurred in the limed soils during the brief growth period of the present experiment (4). Moreover, it has been shown, that the differential solubilities of the di- and tricalcium phosphates are registered definitely when these two phosphates are used as sources of the same quantity of P_2O_5 in Neubauer cultures (4). Hence, since the P_2O_5 recoveries from the lightly prelimed and still mildly acidic soils of Table 1 are comparable on a percentage basis with the recoveries from the more alkaline soils of Table 2, there is no indication that any appreciable fraction of the quickly generated dicalcium phosphate had passed to the tertiary state, and the continued incidence of the quickly formed dicalcium phosphate is considered responsible for the larger uptake of PO_4 from the limed soils.

SUMMARY

Thirty-five soils, including 12 subsoils and eroded phases, were used

in pilot studies by the Neubauer procedure to determine the effect of preliming with $CaCO_3$ and brief "aging" upon the recovery of the P_2O_5 of subsequent incorporations of water-soluble monocalcium phosphate. Initial pH values were used as a guide for the limings at rates within the range of practical incorporations.

In every case the PO_4-uptake from the prelimed and aged soil exceeded that from the unlimed soil. The liming rates for the normal soils were less than those for the subsoils but were more effective in causing higher percentage recoveries of P_2O_5.

The invariable increases in PO_4-uptake are accredited to two concordant factors, i.e., (a) a considerable fraction of the water-soluble acidic phosphate reacted with either the residues of the incorporated carbonate or the resultant calcic silicates to form a precipitate of dicalcium phosphate, and (b) the inherent capacity of the acidic soil to effect PO_4-fixation was diminished substantially by the replacement of the H ion of the colloidal complexes by the Ca of the previously incorporated calcium carbonate. Moreover, the quick transition of the slightly diffusible soluble monocalcium phosphate to the water-insoluble dicalcium phosphate diminishes PO_4-migration and thus retards PO_4-fixation. In the acidic soil, however, the PO_4 of the added phosphate undergoes rapid fixation as iron and aluminum phosphates.

The sum effect of the several factors is that a preparatory liming would assure substantial conversion of an incorporated superphosphate to the readily available form of dicalcium phosphate and promote the continuance of that phosphate for a period sufficient for the initial crop to register an enhancement in PO_4-uptake.

The results point to the advantage of preliming as a means of a more effective utilization of incorporations of superphosphate.

LITERATURE CITED

1. MacIntire, W. H. A new explanation of what happens to superphosphate in limed soils. Tenn. Agr. Exp. Sta. Bul. 176. 1941.
2. ———, Hardin, L. J., and Oldham, F. D. Phosphate fertilizer mixtures: Chemical changes and physical effects induced in mixtures of triple superphosphate with dry and wetted limestone and dolomite. Ind. & Eng. Chem., 28:711–717. 1936.
3. ———, ———, ———, and Hammond, J. W. Development of P_2O_5 insolubility in phosphatic mixtures—the formation of fluorphosphate as its cause. Ind. & Eng. Chem., 29:758–766. 1937.
4. ——— and Hatcher, B. W. Evidence in support of a new concept as to the end-product of superphosphate in limed soils. Soil Sci., 53:43–54. 1942.
5. ——— and Shaw, W. M. Reactivity between dolomite and superphosphate components. Ind. & Eng. Chem. 24:1401–1409. 1932.
6. ——— ———. The transition of citrate-soluble phosphate into citrate-insoluble form in mixtures with limestone and with dolomite. Jour. Amer. Soc. Agron., 26:656–661. 1934.
7. ——— and Shuey, G. A. Chemical changes in mixtures of superphosphate with dolomite and with limestone. Ind. & Eng. Chem., 24:933–941. 1932.
8. Thornton, S. F. Soil and fertilizer studies by means of the Neubauer method. Purdue Univ. Agr. Exp. Sta. Bul. 399. 1935.

EQUIPMENT FOR MAINTAINING CONTROLLED TEMPERATURE AND LOW HUMIDITY IN A SEED STORAGE ROOM[1]

J. L. Cartter[2]

ONE of the principal interests of the agronomist is to strive continually to improve technic in order to measure accurately the differences which are caused by specific factors in a program to improve varieties or cultural practices. This applies equally to field plot technic and to preparation of seed samples for chemical analysis.

The seed is a living organism and when collected for comparative tests in agronomic investigations requiring chemical analysis, it is not only essential that the samples be harvested under comparable conditions but also that after harvest the samples be conditioned and stored under such circumstances that any metabolic changes taking place may be reduced to the minimum. In this respect it is obvious that the moisture content and temperature must be reduced to a point at which the respiration and other enzymatic changes are at a safe minimum and growth of thermophilic seed coat molds restricted.

The soybean contains high percentages of protein and a drying oil, both of which are subject to change resulting in deterioration of the soybean seed under conditions of adverse storage. In conducting the agronomic investigations undertaken by the U. S. Regional Soybean Industrial Products Laboratory, requiring the chemical analysis of a great many samples of soybeans, it was deemed essential to provide storage for the samples at automatically maintained temperature and humidity conditions. In the analysis of soybeans, the oil is determined by percolation of the air-dry ground sample with a petroleum ether. The results have been found to vary with the moisture content,[3] exhibiting a sharp increase at moisture contents between 6 and 8% (Fig. 1). Below and above these percentages the values obtained are relatively uniform; however, at the higher moisture level, more non-lipid material is removed by the solvent, giving incorrect values.

Rate of respiration of some seeds and respiration of molds present on the surface of the seeds has been shown by Bailey[4] to affect the keeping quality of cereal grains and flax seed in storage. As pointed out by Bailey, the distribution of the moisture in the seed is quite significant, especially in the case of oleaginous seeds such as flax containing around 40% oil. The same relationship holds for soybean seed where about 20% of the dry substance is oil. Since the oil is

[1]A publication by the U. S. Regional Soybean Industrial Products Laboratory, a cooperative organization participated in by the Bureaus of Agricultural Chemistry and Engineering and Plant Industry of the U. S. Dept. of Agriculture, and the agricultural experiment stations of the North Central states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Received for publication July 2, 1942.

[2]Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]American Oil Chemists' Society. Report of the soybean analysis committee. Oil and Soap, 16:129–131. 1939.

[4]Bailey, C. H. Respiration in cereal grains and flax seed. Plant Physiol., 15: 257–274. 1940.

immiscible with water, the water would be distributed in the hygroscopic substance of the seed, raising the actual moisture content of these portions to a value considerably above that indicated by the usual moisture determination on the whole seed. Respiration curves would indicate that storage under dry conditions is highly desirable.

The chemical analysis of a large number of soybean seed samples has been undertaken by the Soybean Laboratory for the purpose of studying the effects of environment on composition and to produce improved varieties and strains by breeding and selection. Storage conditions of 16% relative humidity and 70° F were observed to maintain a moisture content in soybeans at or below 5.5% and to meet the general requirements needed for safe storage.

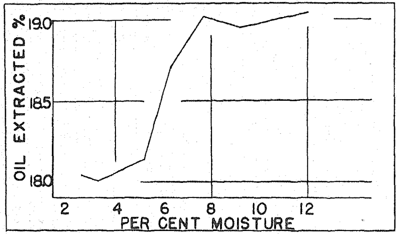


FIG. 1.—Relation of moisture content of soybean seed to the amount of ether extractable material.

At the outset of the program it was felt that to obtain comparable samples for analysis, especially with reference to percentage of crude lipids in soybean seed, the samples submitted for analysis throughout the year should be stored under uniform moisture conditions. Apparatus has been designed at the laboratory for maintaining this low humidity in the seed storage room under both winter and summer conditions. Such equipment should also prove of value to plant breeders in the southeastern part of the United States for the storage of seed stocks, especially of the types of seed that tend to lose vitality rapidly under humid storage conditions.

Several methods of removing moisture from the air were considered. Among them was the use of deliquescent salts such as calcium chloride, lithium chloride, etc., which can be regenerated automatically by distillation of the absorbed moisture. Another method of moisture removal suitable for low humidity installation would be a silica gel dehydrator, also requiring some form of heat to accomplish regeneration of the absorbent. Gas heat, which is commonly used for

this purpose, was not available in the building where the storage room was located. A third method of moisture removal, and the method that appeared most feasible, was to freeze out the excess moisture by mechanical refrigeration.

One of the more simple ways of accomplishing the removal of moisture by refrigeration is to circulate a portion of the room air through a cooling coil, permitting moisture to be condensed upon the coil surface. Since the necessary dew point under the present operating conditions lies well below 32°F, the moisture was removed as ice and some form of frequent automatic and thorough defrosting of the coil had to be provided. The design of the apparatus, which incorporates a very effective method of automatically controlling the defrosting cycle, is given here in detail with the hope that it may aid others in building such an apparatus for the maintenance of low humidities.

CONSTRUCTION OF THE APPARATUS

One of the first considerations in the design of the equipment was the size and construction of the storage room. This storage room, located inside a large concrete seed house, measured 10 feet by 12 feet, with a ceiling height of 8 feet. The room wall construction was 2 by 4 studding with ½-inch celotex sheeting inside and out, with the wall packed with rock wool. A refrigerator door with rubber gasketing was used to avoid excessive air leakage. Ordinary inside paint was used on the walls, though a more moisture-proof paint, such as a hot asphalt coat, would be very desirable on the outside wall of the room. Adequate space was available at the back of the storage room for the location of the air-drying apparatus, a general view of which is given in Fig. 2. The angle iron frame supports the cooling coil (I), the blower (H) for circulating air through the coil, and the dampers for changing the path of the air flow during the defrosting cycle. Under the frame can be seen the refrigerating compressor and the small air compressor used to supply air for the controls. At the right is the switchboard for the equipment.

REFRIGERATING COMPRESSOR AND CONTROLS

For the conditions encountered at the laboratory, a 2 horse power water-cooled Freon[5] refrigeration compressor has proved adequate to maintain the desired room conditions. The compressor and necessary controls are schematically shown in Fig. 3. The compressor is equipped with the usual dual pressure control (B in the diagram) provided to stop the compressor in case of failure of the water supply or other conditions causing excessive head pressure. Gages C and E are provided for observing the suction pressure and head pressure for setting the controls and checking the operating conditions of the system.

The pressurestats D and F, whose functions will be described later, are refrigeration suction pressure controls with mercury switches. These pressurestats are designed to break an electrical circuit upon a

[5]Freon gas (F-12) is not highly toxic and is only dangerous in concentrations high enough to cause an oxygen deficiency.

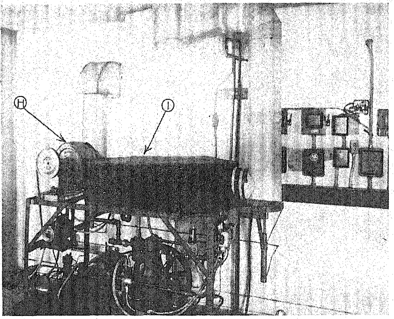


FIG. 2.—Photograph of the equipment for controlling humidity and temperature.

decrease in pressure, but for this special application it was necessary to turn the mercury bulb around in the holder so that the action was reversed, that is, so that the circuit would be made on pressure decrease and broken on pressure increase in the refrigeration suction

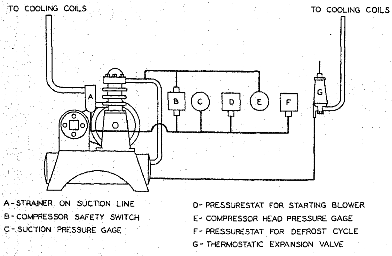


Fig. 3.—Diagram of the refrigerating compressor and the controls.

line. The thermostatic expansion valve G was of the usual adjustable type for low suction pressure installations.

COOLING COIL AND BLOWER

In the construction of the apparatus the capacity of the cooling coil in relation to the compressor capacity and speed of air flow across the coil face is of utmost importance in obtaining adequate drying of the air. It was found by experience that a low velocity of air across the coil was desirable, so the present coil was designed to cool 200 cubic feet of air per minute from 70° F to 16° F, with a Freon (F-12) suction pressure of 0 to 5 pounds. This was accomplished by using a special coil of approximately 1 foot face area by 20 inches deep, constructed from high dispersion "thermek"[6] copper tubing. The floor of the coil housing sloped sufficiently toward one end to provide drainage of the condensed moisture. Precaution should be taken that no puddles of water are allowed to remain standing on the floor of the coil housing after the coil is fully defrosted. A trap was provided in the drain line to prevent moist air entering the system during the running cycle.

The blower (Fig. 2H) for forcing air through the cooling coil (I) was of the turbine wheel type, belt driven to provide a considerable range in speed for adjusting air flow across the cooling coil. This blower was driven through a "V" belt and an adjustable motor drive pulley on a single-speed continuous duty motor.

DAMPERS FOR DEFROSTING COOLING COIL

Positive and rapid defrosting of the cooling coil is essential. In the early stages of the construction of the apparatus an ordinary type of hinged damper was installed at each end of the cooling coil and blower assembly to isolate the coil from the storage room during the defrost cycle and bring in outside air to hasten ice removal from the coil. It was found that air leakage during the defrost period carried appreciable amounts of saturated air into the storage room. To overcome this difficulty, a piston type damper was designed and constructed for the purpose of controlling the direction of air flow.

The damper (Fig. 4) was constructed of 24-gage galvanized iron and held in shape by a brass ring that also served to hold the tripod support for the piston type air motor used to operate the damper. The valve plate in the damper was a flat piece of ⅛-inch aluminum 8¾ inches in diameter mounted on a brass piston rod so that it could move freely between the upper and lower brass seats. These two seats were constructed of ½-inch square brass rod formed into 9-inch circles to fit inside the damper housing, turned in a lathe to form a perfect seat and then soldered to the housing in a plane parallel to the valve face. The flexible mounting of the valve plate to the damper rod took care of any slight lack of perfectly parallel mounting of the two rings. The damper motor consisted of a 1½-inch brass tube mounted as shown in the sketch (Fig. 4). Regular pump leathers adjusted to

[6]Manufactured by the Peerless of America Corporation, Marion, Ind.

operate with very little friction served as the piston packing. An air pressure of 4 or 5 pounds is sufficient to operate the dampers.

AIR CONTROLS FOR DAMPERS

It was found after experimenting with electrically driven damper motors that air operation was much more simple, especially with a damper of this design. No air supply was available so a small air compressor and storage tank was installed. This would not be neces-

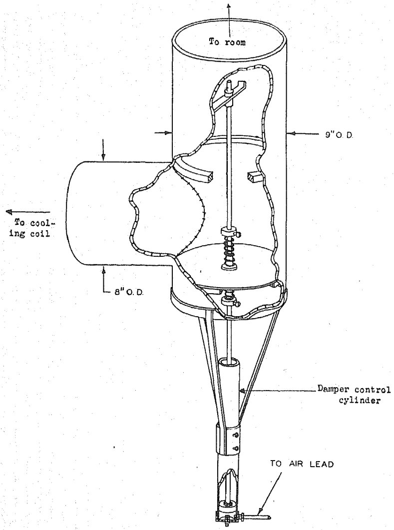


FIG. 4.—Cutaway view of damper used for isolating storage room from refrigerating equipment during the defrosting cycle.

sary in most locations, so the diagram in Fig. 5 was simplified by showing an outside compressed air supply. The three-way solenoid valve J is normally closed, preventing air from entering the branch line. The bleeder is a very small opening that prevents an appreciable build-up of pressure if the reducing valve K leaks. The pressurestat or air switch L opens the thermostat circuit when the dampers are raised. This switch is one of the important features of the apparatus and its function will be described more fully under the discussion of the operation of the defrosting cycle.

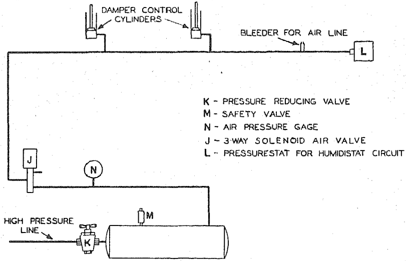


FIG. 5.—Diagram of the air line and controls for operating dampers.

UNIT HEATER

The unit heater for supplying the necessary reheat required to maintain the storage room at 70° F was a locally constructed unit consisting of a 30-inch length of 14-inch diameter galvanized smoke pipe in which six 500-watt heating units (strip heaters) were mounted. An ordinary 12-inch electric fan designed for continuous duty was mounted in one end of the pipe. This fan, which runs continuously, also serves to circulate air in the storage room and has provided quite uniform conditions throughout the entire room.

This unit heater was located at a point in the storage room immediately in front of the duct bringing air from the cooling coil. In this way the cold air from the coil is not allowed to settle but is caught in the air stream of the unit heater and warmed and mixed at once with the other room air. The strip heaters were controlled by the thermostat (Fig. 6) placed a few feet in front of the unit heater and directly in the path of the air stream from the fan. The proper location of this thermostat can be obtained by trial to determine the position which most correctly senses the room conditions and provides closest temperature control.

ELECTRICAL CONTROLS AND WIRING DIAGRAM

The wiring diagram (Fig. 6) shows the single-phase control circuits and the three-phase heater and motor circuits. All relays are shown in their de-energized position.

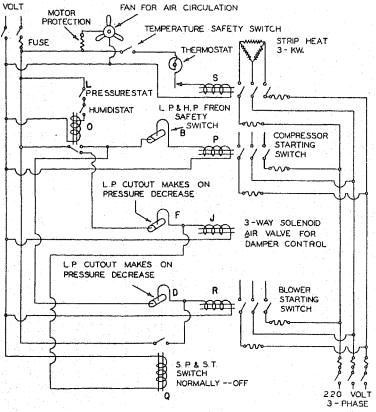


FIG. 6.—Wiring diagram of the equipment used for controlling temperature and humidity.

The strip heaters are controlled through relay S by a thermostat in series with a temperature-safety switch located above the heating units. The switch, labelled "temperature-safety switch" in Fig. 6, is a thermostatic cut-out to disconnect the heater in case of failure of the circulating fan or the controlling thermostat. The circulating fan runs continuously to circulate air in the room as well as through the unit heater.

COOLING COMPRESSOR CIRCUIT

The compressor control circuit consisting of the humidistat in series with the air pressurestat L operates the main control relay marked O in Fig. 6. Through the upper contact of this relay, the com-

TABLE 4.—*Fit of F_2 phenotypic and F_2 genotypic classes.*

Cross	Genotype studied	Phenotypes					P
		AB	Ab	aB	ab		
To a Calculated 9:3:4 Ratio and a 1:2:2:4:1:2 Ratio							
Colsess × Glossy 2	Gl_2gl_2Kk						
Observed number		571.0	97.0	88.0	11.0		
Calculated 9:3:3:1 ratio		487.69	162.56	162.56	54.19		Very small
F_2 Genotypes							
Colsess × Glossy 2	Gl_2Gl_2KK	Gl_2gl_2KK	Gl_2Gl_2Kk	Gl_2gl_2Kk	Gl_2Gl_2kk	Gl_2gl_2kk	
Observed number	302.0	164.0	174.0	537.0	26.0	149.0	
Calculated 1:2:2:4:1:2 ratio	112.67	225.33	225.33	450.67	112.67	225.33	Very small
Nudideficiens × Glossy 2	Gl_2Gl_2II	Gl_2gl_2II	Gl_2Gl_2Ii	Gl_2gl_2Ii			
Observed number	17.0	68.0	48.0	196.0	—	—	
Calculated 1:2:2:4 ratio	36.56	73.11	73.11	146.22	—	—	Very small
To Ratios Calculated with Various Crossover Values							
Colsess × Glossy 2	Gl_2gl_2Kk						
Observed number		571.0	97.0	88.0	11.0	—	
Calculated with 25% C.O.		555.42	94.83	94.83	121.92	—	0.7–0.5
F_2 Genotypes							
Colsess × Glossy 2	Gl_2Gl_2KK	Gl_2gl_2KK	Gl_2Gl_2Kk	Gl_2gl_2Kk	Gl_2Gl_2kk	Gl_2gl_2kk	
Observed number	302.0	164.0	174.0	537.0	26.0	149.0	
Calculated with 25% C.O.	260.30	164.41	164.41	572.52	25.95	164.41	0.1–0.05
Nudideficiens × Glossy 2	Gl_2Gl_2II	Gl_2gl_2II	Gl_2Gl_2Ii	Gl_2gl_2Ii			
Observed number	17.0	68.0	48.0	196.0	—	—	
Calculated with 28% C.O.	12.41	63.83	63.83	188.93	—	—	0.2–0.1

LITERATURE CITED

1. COLLINS, G. N. Measurement of linkage values. Jour. Agr. Res., 27:881–891. 1924.
2. EMERSON, R. A., BEADLE, G. W., and FRASER, A. C. A summary of linkage studies in maize. Cornell Univ. Agr. Exp. Sta. Mem. 180. 1935.
3. HARLAN, H. V., and HAYES, H. K. Occurrence of the fixed intermedium *Hordeum intermedium haxtoni*, in crosses between *H. vulgare pallidum* and *H. distichon palmella*. Jour. Agr. Res., 19:575–591. 1920.
4. IMMER, F. R. Formulae and tables for calculating linkage intensities. Genetics, 15:81–98. 1930.
5. ———. Calculating linkage intensities from F_3 data. Genetics, 19:119–135. 1934.
6. LEONARD, W. H. Inheritance of fertility in the lateral spikelets of barley. Genetics, 27:299–316. 1942.
7. MATHER, K. Measurement of linkage in heredity. Methuen's Monographs on Biological Subjects. 1938.
8. RIDGEWAY, R. Color Standards and Color Nomenclature. Washington. 1912.
9. ROBERTSON, D. W. Inheritance in barley. Genetics, 18:148–158. 1933.
10. ——— and COLEMAN, O. H. The addition of two factor pairs for chlorophyll-deficient seedlings to the linkage groups of barley. Jour. Gen., 39:401–410. 1940.
11. ———, WIEBE, G. A., and IMMER, F. R. A summary of linkage studies in barley. Jour. Amer. Soc. Agron., 33:47–64. 1941.

FLORET AND SEED TYPES IN KENTUCKY BLUEGRASS IN RELATION TO YIELD AND QUALITY OF SEED[1]

J. T. SPENCER AND E. N. FERGUS[2]

MOST of the seed crop of Kentucky bluegrass from the Kentucky-Ohio area is produced on a relatively few farms in the central bluegrass region of Kentucky. Even on these leading seed-producing farms, however, bluegrass is seldom, if ever, grown primarily for seed. It is grown rather for pasture and for conditioning land for tobacco, and the seed is harvested to provide a supplementary income when the bluegrass field is not needed exclusively for pasture during the spring. The amount of seed harvested, therefore, varies greatly from year to year. Four crops of over 900,000 bushels of rough-cured Kentucky bluegrass seed have been produced in the Kentucky-Ohio area since 1925 and five crops of 200,000 bushels or less.[3] The average yield per acre of the former was 13.5 bushels and of the latter 4.7 bushels. Acreages harvested in producing the larger crops ranged from 92,857 to 135,294, and those harvested in producing the smaller ranged from 15,000 to 43,750. The averages for the two groups were 107,038 and 29,173 acres, respectively. The average seasonal prices paid to growers for the rough-cured seed were 80 cents and $1.13 per bushel, respectively, for the larger and smaller crops. In other words, farmers harvest large acreages when the yield per acre is high; small acreages when the yield per acre is low, and receive lower prices per bushel for their large crops than for their small crops.

At the time seed stripping begins, farmers have a reasonably accurate opinion of both the price which the seed will bring and the average yield per acre that may be expected. Since it is clear from the information just presented that price per bushel has little or no influence in determining the size of the seed crop produced, it may be concluded that when yield per acre is good a large acreage is harvested and when low a small acreage is harvested.

The percentage of marketable seed in the rough-cured seed (Fig. 1), commonly designated as "clean-out" percentage, is a good measure of the quality of rough-cured seed. The best quality seed has a "clean-out" of 60 to 65% and low quality seed 40% or less. Thus defined, quality of rough-cured seed has varied widely, especially during the last 5 years when the extremes have been 55% and 22%.

The quality of rough-cured seed seems to be closely correlated with yield per acre. Four crops producing an average yield of 11.4 bushels per acre had an average clean-out of 55%, and three crops producing an average of 4.7 bushels per acre cleaned out 40.8%. In a statistical analysis of the acre yield and clean-out of nine crops for which data

[1]The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station, Lexington, Ky., and is published by permission of the Director. Received for publication July 10, 1942.

[2]Assistant in Agronomy and Agronomist in Charge of Pasture and Forage Crop Investigations, respectively.

[3]BROWN, A. J., and CARD, DANA G. Thirty years of farm prices and production in Kentucky. Ky. Agr. Exp. Sta. Bul. 403. 1940.

are available, the coefficient of correlation, r, was 0.747 ± 0.099.[4] Undoubtedly this correlation is somewhat more apparent than real, since a high percentage of good seed increases the weight of the rough-cured material. It is believed, however, that even allowing for this effect there is a positive correlation between yield of rough-cured seed per acre and the clean-out percentage.

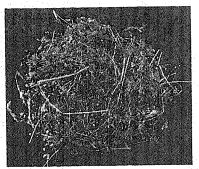


FIG. 1.—Sample of rough-cured Kentucky bluegrass seed. The seed heads have been "stripped" and cured and are now ready for cleaning.

Both farmers and seedsmen hold diverse opinions as to the exact factors responsible for low-quality crops, but usually attribute them to injurious insects or unfavorable weather. More emphasis has probably been placed upon so-called meadow or bluegrass plant bug (*Miris dolobratus*) than upon any other destructive agent. This is a sucking insect which, according to Garman,[5] first made its appearance in Kentucky in 1908. It produces one brood of young each year. In central Kentucky it seems to feed primarily on bluegrass, producing apparently no other visible effects than modern dwarfing of the heads.[6] Among climatic factors, the effects of drouth and of late spring frost have aroused most speculation. Soil factors have received little attention from the layman but are being considered in certain research studies, and disease may not be ignored.

MATERIALS AND METHODS

Preliminary to an investigation of factors that might be responsible for the occurrence of low-quality seed crops in bluegrass, a study was made in 1940 and 1941 of the conditions within the florets at the time of seed harvest. Mature heads were obtained from pastures and curing ricks in the central bluegrass region of Kentucky and from individual bluegrass selections in the grass nursery on the experiment station farm at Lexington. The florets were examined under a dissecting microscope and the lemma and palea separated in order to expose the reproductive organs or the seeds.

OBSERVATIONS AND RESULTS

Examination of several thousand florets and seeds revealed that they could conveniently be classified into eight categories or "types". Each type is illustrated in Fig. 2.

[4]Data on marketable seed recovered from rough-cured seed were furnished by Dr. Dana G. Card, assistant in markets, Department of Markets and Rural Finance, Kentucky Agricultural Experiment Station.

[5]GARMAN, H. Two important enemies of bluegrass pastures. Ky. Agr. Exp. Sta. Bul. 265. 1926.

[6]JEWETT, H. H. Unpublished data.

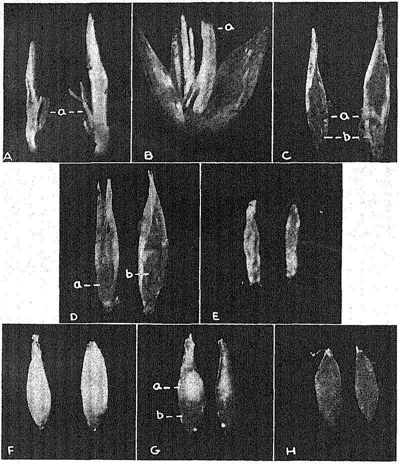


FIG. 2.—Floret and seed types in Kentucky bluegrass. A, type A florets; ovary and stamens both present; anthers (a) apparently have never produced pollen. The pistil is not visible in the picture and the lemma has been removed. B, type B florets; pistil present but not visible in the picture; stamens present (apparently not extruded at anthesis) and anthers (a) containing pollen (no dehiscence). C, type C florets; only the pistil remains within the floret, the anthers apparently having been extruded at the time of anthesis. Style and stigma indicated by (a) and ovary by (b). Lemma removed. D, type D florets; seed partially developed. Ovary (a) about one-third as large as a full-sized seed; ovary (b) about two-thirds as large as a full-sized seed. Lemma removed. E, type E seeds; seeds either partially or completely shriveled. The two seeds pictured are completely shriveled. F, type F seeds; endosperm entirely soft. G, type G seeds; endosperm partly soft (a) and partly hard (b). H, type H seeds; endosperm almost or entirely hard (×30).

Type A.—Both stamens and pistil are present within the floret at the time of crop harvest. The ovary has undergone no development toward production of a seed insofar as size is a criterion. The anthers are shrunken and empty and apparently produced no pollen.

Type B.—Both stamens and pistil are present within the floret. It differs from type A only in that the anthers contain pollen. The anthers apparently were not extruded and did not undergo dehiscence.

Type C.—Only the pistil remains within the floret. The anthers apparently were extruded at the normal time of anthesis.

Type D.—The ovary has undergone partial development toward production of a seed insofar as size is a criterion. The developing seed may vary from slightly larger than the ovary to almost two thirds as large as a full-sized seed.

Type E.—The seed coat is apparently completely developed, but the seed is shriveled. It is often difficult to determine whether a particular seed should be classified as type D or type E.

Type F.—The seed is fully developed. It is opaque when viewed in transmitted light, and the entire endosperm is white and has a mealy texture; that is, it is soft endosperm. This seed type is probably closely related to type E, the shriveled seed group. The small amount of endosperm in type E seeds usually is soft.

Type G.—The seeds contain both soft and hard endosperm.

Type H.—The endosperm is nearly or entirely hard. These seeds are translucent when viewed in transmitted light, and the endosperm has a flinty texture; that is, it is hard endosperm.

The anthers were extruded from practically all florets classified as C to H.

The frequency of occurrence of each of the floret and seed types was determined in samples collected in 1940 and 1941. Results are given here only for 1941, since all the types occurred in both years. The 1941 seed crop, however, was inferior in quality to the 1940 crop, having an estimated "clean-out" of 22% as compared with 30% for the latter. Two hundred florets were selected at random for study from several heads of each sample. Twenty-three samples were obtained from pastures and curing ricks in five counties of the central bluegrass region in 1941 and the florets studied. The mean and range of frequencies of floret and seed types found are reported in Table 1.

TABLE 1.—*Frequency of occurrence of floret and seed types of Kentucky bluegrass in 23 samples obtained from pastures and curing ricks in five counties in 1941.*

	Type*							
	A	B	C	D	E	F	G	H
Mean frequency, %	9.1	17.0	19.6	16.6	9.6	4.3	1.4	22.5
Range, %	1–32	1–49	2–43	7–32	4–21	1–10	0–4	1–50

*See text for description of types.

The range was considerable for nearly all the types. The hard seeds ranged from 1 to 50% and averaged 22.5% for the entire group of samples. Only 4.3% of the florets contained seeds with wholly soft endosperm. Considering the total number of seeds, however, about one seed in seven was of the soft-endosperm type. Fully 46% of all the florets contained ovaries which underwent no development toward

the production of a seed (sum of types A, B, and C in Table 1) and 72% failed to yield a completely developed seed (sum of types A, B, C, D, and E in Table 1).

Floret and type frequencies observed in 1941 from 25 individual plant selections in block A of the bluegrass nursery on the experiment station farm at Lexington are presented in Table 2.

TABLE 2.—*Frequency of occurrence of floret and seed types of Kentucky bluegrass in 25 individual plant selections of the grass nursery, block A, 1941.*

	Type*							
	A	B	C	D	E	F	G	H
Mean frequency, %	8.0	16.0	25.9	20.7	16.4	6.6	1.3	7.1
Range, %	1–24	8–37	9–50	14–33	6–36	0–16	0–5	0–26

*See text for description of types.

Seed production was distinctly lower among the 25 plants of block A as a whole (Table 2) in 1941 than in the samples from pastures and curing ricks in the same year (Table 1). The best seed production by any plant was only 26% of seeds with hard endosperm. One plant produced no seeds of any kind.

Perhaps the lower percentage of hard seed in the heads from block A in 1941 than in the heads from the pastures and curing ricks may be because the former were from plants that had been in the same location for 6 years without benefit of associated legumes or fertilizer treatment. This assumption receives some confirmation from studies made of plant and seed type frequencies in 16 individual plants in block B in 1941. These plants were 3 years old, considerably more vigorous than those in block A, and produced 19.3% of hard seed (Table 3) as compared with 7.1% of hard seed in the older plants in block A (Table 2). The favorable percentage of hard seed in the block B plants occurred largely because more of the seed matured, that is, there were fewer of seed types D and E. However, the percentage of aborted florets appears to be very little lower in the plants of block A than in the more vigorous plants of block B.

TABLE 3.—*Frequency of occurrence of floret and seed types of Kentucky bluegrass in 16 individual selections of the grass nursery, block B, 1941.*

	Type*							
	A	B	C	D	E	F	G	H
Mean frequency, %	9.6	14.3	23.9	11.9	14.1	7.4	1.4	19.3
Range, %	1–26	1–30	9–48	7–18	3–33	2–27	0–4	3–32

*See text for description of types.

Whether differences between seed types designated as F, G, and H have any practical significance has not been determined. However, preliminary studies indicate that seeds having wholly hard endosperm germinate substantially better than those having wholly soft endosperm.

If seeds with wholly hard endosperm are better for sowing, obviously findings similar to those in Tables 2 and 3 must receive consideration in attempting to produce better strains of Kentucky bluegrass. Unfortunately, the data obtained from blocks A and B are not encouraging. The 41 plants included in the samplings are representative of a large population of bluegrass strains, yet no plant produced more than 32% of hard seed. Data obtained from plants sampled at random in the same population in 1940, however, were somewhat better; one plant produced 76% of hard seed.

The occurrence of both hard- and soft-endosperm seeds in a head of Kentucky bluegrass raises some important questions. Apparently the situation is similar morphologically to the well-known one in wheat, especialy hard red winter, in which the much-studied "yellowberry" is the variant with which bluegrass seed type G may be compared. The similarity of variant seed types in these two grasses suggests environmental and genetic causes.

It is recognized, of course, that any satisfactory conception of the ovarial development in bluegrass depends in part upon a knowledge of the distribution of ovary and seed types in the panicle, and a preliminary attempt was made to obtain this information. Although further study is necessary, it appears that the seeds with hard endosperm occur most frequently in the lower florets of the spikelet, and that the upper florets show an increasing percentage of ovaries which have undergone no development toward the production of seeds. It also seems that the florets in the upper portions of the inflorescence more frequently produce seeds with hard endosperm than do those in the lower portions.

SUMMARY

Crops of rough-cured Kentucky bluegrass seed produced in the Kentucky-Ohio area vary widely in yield per acre and in quality. The latter is measured in terms of the percentage of marketable seed that it contains, or "clean-out" percentage. The correlation between clean-out percentage and yield per acre is statistically significant, a fact suggesting that the causes of each are, in part, identical. Farmers hold diverse opinions concerning the probable causes. Perhaps most of them believe the bluegrass plant bug (*Miris dolobratus*) to be the usual cause.

Studies made of two crops of bluegrass to determine the condition of mature spikelets and florets as related to seed quality show that the florets can be classified into eight distinct "types" upon the basis of the condition of the reproductive organs and the endosperm characteristics of the seeds.

A cross-section sampling of the 1941 seed crop disclosed that 46% of all the florets contained ovaries which had undergone no develop-

ment towards the production of a seed and 72% of all the florets failed to yield a completely developed seed; that 22.5% of the florets produced seeds with hard endosperm, 4.3% produced seeds with wholly soft endosperm, and 1.4% produced seeds whose endosperms were both soft and hard.

Individual bluegrass plant selections showed a ranged in hard seed production of 0 to 32% in 1941 and 7 to 76% in 1940.

HERITABLE VARIATIONS IN SEED SET UNDER BAG AMONG PLANTS OF ORCHARD GRASS, *DACTYLIS GLOMERATA* L.[1]

W. M. MYERS[2]

IN the improvement of naturally cross-pollinated species such as *Dactylis glomerata* L., the most facile method of producing strains which are uniform for desirable characters seems to be first to fix those characters in a relatively homozygous condition by inbreeding. Since *D. glomerata* behaves cytogenetically like an autotetraploid, as has been shown by Müntzing (6, 7),[3] Myers and Hill (11, 12, 13), and Myers (8, 9), it is almost imperative that the inbreeding be accomplished by self-pollination; according to the calculations of Bartlett and Haldane (1), the approach to homozygosity accompanying sib-mating of plants of an autotetraploid may be expected to be very slow. Consequently, a knowledge of the heritable variations in self-fertility is basic to any intelligent planning of a varietal improvement program.

The most reliable criterion of the self-fertility of any plant would be obtained from seed set with space isolation. However, space isolation obviously is impossible where hundreds or thousands of plants are being investigated and, as a result, the plant breeder has been forced to adopt some artificial barrier to cross-pollination. For this purpose, parchment paper bags for enclosing the panicles prior to flowering have been used for the grasses by most investigators and were adopted for the experiments presented in this paper. Since the bag may have a deleterious effect upon seed setting, it can not be concluded that seed set under bag gives an accurate measure of self-fertility. Nevertheless, if inbreeding is to be accomplished by most plant breeders by the use of paper bags, "ability to set seed under bag" is the character of greater practical importance.

LITERATURE REVIEW

Rather comprehensive reviews of the literature relating to self- and cross-fertility among the forage grass species have been presented by Beddows (2), Nilsson (14), and, more recently, by Smith (16). In orchard grass, Frandsen (4), Troll (18), Hayes and Garber (5), Wolfe and Kipps (19), Stapledon (17), Nilsson (14), Schultz (15), and Smith (16) found that the percentage of florets which set seed was considerably lower on the average when the plants were self-pollinated than under conditions of open-pollination. Most of these authors also observed a considerable variation among different plants in seed set with self-pollination. Nilsson (14), Stapledon (17), and Schultz (15) reported that some plants approached complete self-fertility.

Little information is available in the literature regarding the inheritance of this character. Hayes and Garber (5) reported that inbred plants from the "high"

[1]Contribution No. 35 of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Northeastern States. Received for publication July 13, 1942.

[2]Geneticist.

[3]Figures in parenthesis refer to "Literature Cited", p. 1050.

line set more selfed seed than inbred plants from the "low" line. Furthermore, the percentage seed set of the inbreds exceeded that of the parents. In these experiments, however, the number of plants used was small. Schultz (15) reported a nearly significant correlation coefficient (r=.32) between self-fertility values of parental plants and their 1-year selfed progenies. No data were given on the average seed set of the inbreds as compared with their parents, although Schultz (15) stated that the 1- and 2-year inbreds again ranged from apparently complete fertility to high self-sterility. Stapledon (17) found no significant tendency for self-fertility to decrease in inbred generations, and Nilsson (14) reported similar results.

MATERIALS AND METHODS

The materials and methods for obtaining selfed seed set are described (10) in detail, except for treatment of the inbred progenies, and need not be repeated here. Only part of the inbred plants flowered in 1939, permitting the collection of but fragmentary data during that summer. All of the data for the inbreds reported in this paper were obtained in 1940. Three bags, each enclosing four panicles, were placed on each inbred (I_1) plant and the average number of seeds per panicle was determined for each bag.

For determination of open-pollinated seed set, four panicles were selected in 1940 from each plant, both parental clone and I_1, from which data were obtained on seed set under bag. Insofar as possible, panicles similar in size and maturity to those bagged for selfing were used. To prevent shattering of seed, the four selected panicles on each plant were enclosed in a bag prior to seed ripening but after completion of flowering. The total number of seeds from the panicles were counted and seed set expressed as average number of seeds per panicle.

EXPERIMENTAL RESULTS

RANGE IN ABILITY TO SET SEED UNDER BAG AMONG PLANTS FROM OPEN-POLLINATED SEED

The 497 plants bagged in 1938 ranged in number of seeds per panicle set under bag from 0 to over 200 (Table 1). Only one bag enclosing six panicles was used on each plant. In view of the extreme random variation obtained in seed set under bag it is apparent that the determination for any single plant is not very accurate. (See Myers, 10.) The data do show, however, the general trend in seed-

TABLE 1.—*Range in ability to set seed under bag of plants of orchard grass in 1938.*

Year	No. of seed set per panicle												Total No.
	0	1-	1-5	6-10	11-15	16-20	21-30	31-50	51-100	101-150	151-200	Over 200	
Number of plants..	39	51	142	69	46	22	33	40	38	13	3	2	497
Per cent of plants..	7.8	10.3	28.6	13.9	9.2	4.4	6.6	8.0	7.6	2.4	0.6	0.4	—

setting ability. Of the 497 plants, 7.8% failed to set seed and another 10.3% produced an average of less than one seed per panicle. At the other extreme, 3.4% of the plants produced more than 100 seeds per panicle.

SEED SET UNDER BAG OF PARENTAL CLONES AND THEIR FIRST-GENERATION INBRED PROGENIES

The analysis of variance of number of seeds per panicle set under bag by the parental clones in 1939 and 1940 has been summarized (10) and repetition is unnecessary. It was apparent that statistically highly significant differences among clones obtained. Since data on seed set were collected for the inbreds in 1940, data collected on the parental clones during the same year were used for comparison of seed set between parent and inbred (Table 2).

Complete data were available from the inbred progenies of 46 clones. In 1940 the clones ranged from 1.8 seeds to 145.6 seeds per panicle, while the range of the average seed-set of the inbred progenies was from 1.3 to 51.8 seeds per panicle. The correlation coefficient of seed set of parent with seed set of progeny was 0.618, which with 44 degrees of freedom is highly significant statistically (3, Table VA). The average number of seeds per panicle of the 46 clones was 40.2, while that of the inbreds was 14.9, only 37.0% of the seed set of the clone. The difference between means is statistically significant ($t = 3.992$ with 90 D/F). Of the 48 comparisons, seed set of the clone was higher than the average of its inbred progeny in 35 cases and lower in 11. Ten of these 11 cases occurred among the 20 clones with lowest seed set.

The range of the I_1 plants in each family in number of seed per panicle set under bag is shown in Table 2. One or more plants failed to set seed in each of 22 of the 46 progenies, while less than one seed per panicle was obtained on at least one plant in each of 22 additional progenies. On the other hand, in 35 of the 46 progenies, one or more plants were obtained which set more seed under bag than the parental clone. This tendency for some inbreds to exceed the parent is particularly common among the progenies of clones with low seed set.

Frequency distributions on the basis of seed set under bag of the plants of 16 inbred progenies are shown in Table 3. These 16 progenies were selected arbitrarily to represent the range of the parental clones in seed-setting ability. Frequency distributions of the remaining 30 inbred progenies have not been presented in the interest of economy of space since the results are similar to those given in Table 3. Several characteristics of the distribution may be mentioned. With the exception of progenies of the low seed-setting clones, there is a wide range of distribution. Furthermore, the distributions are, in general, unimodal with a distinct skewness in the direction of low seed-setting. The majority of the inbred plants set less seed than their parental clones. This situation obtains even in those progenies with a higher average number of seeds than their parents. Examination of the frequency distributions reveals that segregation for number of seeds per panicle set under bag can not be explained upon a simple Mendelian basis. The apparent genetical complexity of this character is not

TABLE 2.—*Comparative seed set under bag and under open-pollination of parental clones (C) and their first-generation inbred (I_1) families in 1940.*

Clone No.	No. seeds per panicle set under bag			No. seeds per panicle set in open		Selfed/open seed set × 100		
	C	I_1	Range of I_1	C	I_1	C	I_1	Range of I_1
14(11).....	1.8	10.7	1.6– 43.0	285.3	359.4	0.8	4.2	0.4– 19.3
11(18).....	2.2	16.6	0.0–133.7	45.0	70.3	5.1	22.8	1.4– 99.7
48(270)....	2.5	2.1	0.1– 11.0	281.3	225.4	0.9	1.1	0.1– 5.3
1(22)......	2.8	10.3	0.4– 41.3	161.0	76.8	2.2	12.5	1.1– 24.0
48(172)....	3.6	8.1	0.1– 61.7	256.7	161.2	2.0	7.5	0.5– 48.9
2(3).......	4.1	1.3	0.1– 5.7	402.3	225.6	1.2	1.1	0.0– 10.1
48(6)......	4.8	9.2	0.8– 50.7	235.7	233.7	2.0	6.4	0.7– 56.3
47(22).....	5.8	6.8	0.0– 65.7	106.7	100.6	6.7	8.7	0.0– 80.3
8(19)......	6.3	7.9	0.0– 51.7	252.3	85.8	2.4	12.8	0.0– 44.4
18(15).....	7.4	2.1	0.0– 9.0	15.7	8.7	63.9	20.8	20.8
48(226)....	7.9	15.3	0.5–123.5	243.7	350.0	3.2	6.2	0.0– 59.4
6(7).......	8.8	7.6	0.2– 42.0	118.3	121.2	8.2	7.3	0.2– 24.7
8(13)......	10.1	4.8	0.0–158.0	194.7	32.2	5.9	11.3	0.0–100.0
6(9).......	12.6	1.2	0.0– 4.0	143.3	44.7	15.3	6.7	0.0– 38.9
48(49).....	12.8	10.8	0.0– 71.0	272.7	140.6	5.7	15.0	0.0– 80.7
2(11)......	13.3	8.7	0.7– 24.0	270.7	153.6	6.9	5.9	0.6– 12.5
14(13).....	14.4	8.3	0.3– 48.7	156.7	130.7	13.9	7.9	0.3– 45.5
42(24).....	15.1	21.2	0.0–216.0	255.3	244.2	8.5	12.4	0.0–100.0
1(8).......	15.8	4.8	0.2– 15.3	133.0	97.6	14.3	6.8	0.7– 29.3
48(28).....	16.4	32.9	4.0– 98.7	181.7	142.8	18.1	15.5	1.5– 48.0
7(20)......	16.5	2.3	0.0– 10.0	274.0	41.0	9.8	2.0	0.5– 4.8
4(20)......	18.3	9.3	1.3– 32.0	305.3	191.1	7.2	6.4	0.7– 29.1
6(12)......	19.2	11.2	0.0– 98.3	180.7	290.8	14.1	7.2	0.0– 21.4
42(5)......	20.4	2.7	0.0– 24.7	77.7	131.6	33.9	3.5	0.0– 20.0
48(23).....	26.1	20.5	0.2–115.7	311.3	165.2	8.4	12.3	0.3– 54.7
1(23)......	28.0	31.8	0.0–102.0	301.0	148.4	10.7	30.7	0.0– 84.4
2(20)......	28.2	26.8	0.0–122.3	156.7	94.7	21.7	25.0	0.0–103.6
46(14).....	35.1	2.3	0.2– 8.3	330.3	158.4	10.6	3.1	0.0– 16.7
4(18)......	41.2	19.8	0.7– 98.3	356.7	247.6	13.7	11.0	0.4– 62.3
20(14).....	43.3	17.0	0.0–122.3	257.3	92.6	17.8	21.8	0.0– 59.8
48(48).....	44.7	3.9	0.8– 15.7	176.7	47.0	25.4	4.4	1.4– 13.9
1(1).......	45.6	10.8	0.0– 65.5	134.0	27.8	36.8	32.8	0.0–144.4
46(11).....	50.8	17.2	0.5– 57.0	171.3	197.4	41.6	11.6	0.3– 62.4
48(25).....	60.9	7.6	0.0– 64.0	289.7	100.9	29.2	6.8	0.0– 54.2
48(43).....	62.6	11.3	0.2– 45.7	186.3	115.4	40.4	20.3	0.2–100.0
14(12).....	63.4	16.4	0.1– 92.7	146.3	43.6	21.4	23.4	0.4–121.6
2(21)......	67.2	29.4	0.0–295.3	276.0	190.3	6.9	18.6	0.0–100.0
48(92).....	73.9	13.3	0.0– 59.3	174.0	27.2	44.6	27.2	0.0–166.6
6(13)......	93.7	37.4	0.3–124.0	232.0	139.5	49.1	40.8	0.3–116.1
4(4).......	93.9	14.2	0.7– 89.0	159.3	70.6	54.5	29.7	0.9–193.3
42(23).....	95.7	51.8	0.0–228.5	245.0	165.5	54.1	44.0	0.0–135.9
1(13)......	107.4	15.3	0.4– 65.0	208.7	74.4	52.6	30.9	0.8–151.5
1(12)......	113.2	26.3	0.0–103.7	297.3	155.1	33.5	20.8	0.0– 95.8
20(11).....	140.9	23.5	0.0–107.5	359.3	135.6	31.6	23.0	0.0–160.7
47(5)......	143.7	31.2	0.0–153.0	408.3	154.1	35.2	25.4	0.0–153.0
48(267)....	145.6	39.4	0.8–243.0	349.3	175.9	45.4	25.0	0.3–100.0
Average....	40.2	14.9		225.6	138.8	20.4	15.2	

surprising, however. The extreme random variation in number of seeds per panicle (10) would tend to obscure any segregation classes. Furthermore, number of seeds per panicle set under bag is a com-

TABLE 3.—*Distribution based on number of seeds per panicle set under bag of plants of 16 inbred families derived from parents which were widely different in seed-setting ability.*

Clone No.	Average		Number of I_1 plants setting indicated number of seeds									
	C	I_1	0–1	1–10	11–20	21–40	41–60	61–80	81–100	101–140	141–180	181–300
48(270)	2.5	2.1	8	15	1	0	0	0	0	0	0	0
48(172)	3.6	8.1	2	8	0	0	0	1	0	0	0	0
2(3)	4.1	1.3	16	10	0	0	0	0	0	0	0	0
48(6)	4.8	9.2	1	13	5	0	1	0	0	0	0	0
47(22)	5.8	6.8	23	33	8	5	1	1	0	0	0	0
8(19)	6.3	7.9	11	14	3	1	2	0	0	0	0	0
8(13)	10.1	4.8	32	20	5	0	0	0	0	0	1	0
42(24)	15.1	21.2	19	36	13	9	3	4	1	3	1	1
42(5)	20.4	2.7	18	16	0	1	0	0	0	0	0	0
2(21)	67.2	29.4	12	24	13	15	6	2	5	1	2	1
6(13)	93.7	37.4	2	5	11	7	8	6	2	2	0	0
4(4)	93.9	14.2	6	28	16	9	5	0	1	0	0	0
42(23)	95.7	51.8	4	8	9	15	8	13	1	4	2	3
1(12)	113.2	26.3	5	18	6	12	8	1	3	1	0	0
47(5)	143.7	31.2	3	19	13	21	15	4	2	2	1	0
48(267)	145.6	39.4	3	17	7	11	4	7	1	4	0	2

plex consisting of number of florets per panicle, general fertility, and self fertility.

SEED SET UNDER OPEN-POLLINATION

The generally lower seed set under bag of the inbreds as compared with their parental clones may have resulted from a reduction in number of florets per panicle, general fertility, self-fertility, or any combination of these factors. Reduction in number of florets per panicle and in general fertility would be reflected in a general reduction of the number of seeds per panicle set with open-pollination. That such reduction occurred may be seen in Table 2. Of the 46 comparisons, the open seed set of the clone was higher than that of the inbred in 39 and lower than that of the inbred in 7 cases. The average number of seeds per panicle under open-pollination was 225.6 for all of the clones and 138.8 for their inbred progenies. The difference is statistically significant ($t = 4.868$ with 90 D/F). The number of seeds per panicle of the clones ranged from 15.7 to 408.3. The correlation coefficient of the clones with their inbred progenies was 0.493, a value greater than r for P of 0.01 (3, Table VA), indicating heritable differences in this character. The question arises whether the differences in ability to set seed in the open have accounted for the differences in ability to set seed under bag. The correlation coefficient of number of seeds per panicle set under bag with number set under open-pollination on the clones was 0.354, which gives P of about 0.02. It may be concluded that all of the variability in seed set under bag can not be accounted for by differences in number of florets per panicle or in general fertility.

PERCENTAGE OF NORMAL SEED SET UNDER BAG

Percentage seed set was calculated from the formula,

$$\frac{\text{number of seeds per panicle under bag}}{\text{number of seeds per panicle in the open}} \times 100.$$

The parental clones ranged from 0.8 to 54.5% (Table 2). Data from three replications were obtained from 44 of the clones and an analysis of variance was calculated for these (Table 4). The use of the analysis of variance for such divergent values as these is a questionable procedure. The magnitude of the differences among clones was so great as to leave little question of their significance. The value of F obtained (Table 4) was in agreement with that assumption. The analysis is shown particularly to emphasize the large error variance obtained for this character.

That some of the differences among clones are heritable is indicated by the correlation coefficient of 0.677 (exceeds P of 0.01) between percentage seed set of the clones and of their inbred progenies.

TABLE 4.—*Analysis of variance of percentage seed set of 44 clones in 1940.*

Variation due to	D/F	Sums of squares	Mean square	F
Clones	43	36,000	837.22	6.83*
Replications	2	397	198.38	—
Error	86	10,539	122.55	—

*Exceeds F for P of 0.01 with appropriate D/F.

Among the 46 comparisons of clone with inbred progeny, the percentage seed set of the clone was higher in 28 and lower in 18 cases. The average of all clones was 20.4% and of all inbred progenies 15.2%. This difference is not significant statistically ($t = 1.676$ with 90 D/F). However, since percentages are involved in this comparison, the results must be interpreted with caution. Evidence for a reduction in self-fertility accompanying inbreeding is obtained from the frequency distributions of the plants of 16 inbred progenies (Table 5). In most progenies, the distributions are skewed in the direction of low fertility, although this tendency is less marked than that for number of seeds per panicle under bag shown in Table 3.

From the results reported it may be concluded that general reduction in seed-setting ability, either from reduced number of florets per panicle or reduced fertility, or both, accounts for a considerable portion of the reduction in seed set under bag which was found to accompany inbreeding. There is, in addition, slight but not conclusive evidence of a reduction in self-fertility with inbreeding.

RELATION OF REDUCTION IN VIGOR TO REDUCED SEED SET UNDER BAG ACCOMPANYING INBREEDING

In 1940, estimations were made of the relative vigor (total green weight) of each inbred plant compared with its parental clone as 100%. The average vigor of the 46 inbred progenies reported in Table 2 varied from 40 to 105% and the differences among inbred

families were statistically significant (unpublished data). The reduction in seed set under bag accompanying inbreeding has been shown to result to a considerable degree from reduction in general seed-setting ability. It is possible that this reduced seed setting is a reflection of the generally lower vigor of the inbreds. If so, within each inbred family there should be a positive correlation between number of seeds per panicle set under bag and percentage vigor. Correlated data were available for 11 to 26 plants in 35 inbred families and a correlation coefficient was calculated for each. Eleven of the 35 correlation coefficients were negative but none of these was statistically significant. Of the 24 positive values, 8 were 0.1 or less and 5 were between 0.1 and 0.2. Three of the 24 reached or exceeded the conventional level of significance. These were 0.469 ($P=0.05$), 0.517 ($P=0.02$), and 0.733 ($P=0.01$). The results indicate that reduced growth vigor has not been a major factor in conditioning reduction in seed set under bag.

TABLE 5.—*Distribution of percentage selfed seed set by plants of 16 inbred families derived from parents which were widely different in percentage seed set.*

Clone No.	Average		Number of I_1 plants setting indicated percentage of selfed seed									
	C	I_1	0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100
48(270)	0.9	1.1	25	0	0	0	0	0	0	0	0	0
2(3)	1.2	1.1	22	1	0	0	0	0	0	0	0	0
48(172)	2.0	7.5	9	0	0	0	1	0	0	0	0	0
48(6)	2.0	6.4	16	2	0	0	0	1	0	0	0	0
8(19)	2.4	12.8	12	1	1	2	2	0	0	0	0	0
8(13)	5.9	11.3	34	2	2	1	1	0	1	0	1	1
47(22)	6.7	8.7	55	8	1	3	1	0	0	0	1	0
2(21)	6.9	18.6	39	11	5	7	1	3	1	1	0	3
42(24)	8.5	12.4	61	10	6	2	1	2	0	0	0	3
1(12)	33.5	20.8	20	11	7	3	3	1	2	1	0	1
42(5)	33.9	3.5	18	3	0	0	0	0	0	0	0	0
47(5)*	35.2	25.4	27	19	7	8	5	2	3	0	3	0
48(267)	45.4	25.0	20	11	5	5	2	4	1	0	0	2
6(13)†	49.1	40.8	12	4	5	3	2	3	3	1	0	2
42(23)‡	54.1	44.0	15	7	9	5	1	4	4	0	1	5
4(4)§	54.5	29.7	25	10	11	6	6	3	3	1	0	0

*Two additional plants were 112 and 153%.
†Two additional plants with 116 and 141%.
‡Five additional plants with 114, 116, 118, 119, and 136%.
§Two additional plants were 165 and 193%.

There has been a general opinion among forage plant breeders that plants with greater self-fertility will tend to produce more vigorous inbreds than will those with lower self-fertility. This opinion has been based on the assumption that partial self-pollination of the more self-fertile plants in nature has resulted in a greater degree of homozygosity associated with self-fertility. In the material used in this study, the correlation coefficient of percentage seed set of the parent with average vigor of its inbred progeny was −0.279. P is about 0.05 and

the value may be considered of doubtful statistical significance. Nevertheless, the fact that a nearly significant negative value was obtained where a positive one was expected suggests that the hypothesis is incorrect, at least so far as this material is concerned.

DISCUSSION

As pointed out previously, a knowledge of the heritable variations in self-fertility (or ability to set seed under bag) is of considerable importance in species in which inbreeding is to be practiced. It seems appropriate, therefore, to examine the results of these investigations in relation to this problem.

A normal spaced plant of orchard grass in its second year of growth will produce at State College, Pa., from 5 to well over 100 good panicles. Among the 497 plants which were bagged in 1938, 81.9% set more than one seed per panicle under bag and 63.3% set more than five seeds per panicle. Therefore, it may be concluded that between 60 and 80% of these plants would have produced sufficient seed under bag for the establishment of an adequate first-inbred generation. The remaining 20 to 30% of the plants would not be usable in a program where inbreeding is accomplished by self-pollination. Since no relation between agronomic desirability and ability to set seed under bag has been noted, a corresponding proportion of the selected plants would need to be eliminated on this basis. Thus, inability to set seed under bag presents an obstacle at the very beginning of the inbreeding program.

The limitation imposed by low seed set under bag is even more serious among the I_1 plants since there was found a general reduction in seed setting accompanying inbreeding. Examination of Table 3 reveals that among the progenies of the less self-fertile plants, relatively few set more than five seeds per panicle. Even among the progenies of the most self-fertile parents, a considerable portion of the inbreds set less than five seeds. This behavior imposes three serious limitations upon the inbreeding program, *viz.*, (a) many additional plants must be grown in each I_1 progeny to ensure the presence of plants that will set seed under bag, (b) additional plants must be bagged in order to discover the ones capable of setting seed, and (c) selection of I_1 parents for the I_2 generation will be limited to that portion of each I_1 family which sets sufficient seed. As a result of the first and second limitations, fewer lines can be carried with the same facilities, while as a result of the third limitation, the effectiveness of selection will be greatly reduced.

Although the results obtained in these investigations indicate that inability on the part of many plants of orchard grass to set seed well under bag may prove to be a serious obstacle to inbreeding by self-pollination, they do not indicate that improvement by this method of breeding is impossible. As has been stated above, first-inbred generation progenies may be established from a majority of the plants of orchard grass. Furthermore, even among the I_1 progenies of plants with low seed set, plants are obtained which set sufficient seed to enable the plant breeder to maintain the line at least into the I_2

generation. More data on later generations of inbreeding will be required before a decision can be reached regarding the feasibility of inbreeding orchard grass by self-pollination.

In this investigation, ability to set seed under bag was positively and significantly correlated with ability to set seed with open-pollination. Nilsson (14) and Smith (16) observed a similar relationship of self- with cross-fertility in other grass species. The reason for the relationship observed in this study is rather apparent. Any factor reducing female fertility of a plant would cause a corresponding decrease in number of seeds produced under bag as well as with open-pollination. Furthermore, number of florets per panicle no doubt is an important factor conditioning variation in number of seeds per panicle.

SUMMARY

In 1938, panicles on 497 plants of orchard grass (*Dactylis glomerata* L.) from open-pollinated populations were enclosed in parchment bags prior to flowering. The number of seeds per panicle set under bag varied on the different plants from 0 to over 200.

In 1940, data on number of seeds per panicle set under bag and with open-pollination were obtained from 46 replicated parental clones and their first-generation inbred (I_1) progenies. The parental clones ranged from 1.8 to 145.6 seeds per panicle set under bag and the parent-inbred progeny correlation coefficient for this character was statistically significant ($r=0.618$, $D/F=44$). The average number of seeds per panicle set under bag was 40.2 for the 46 clones and 14.9 for their inbred progenies. The difference was highly significant statistically. No simple Mendelian basis for inheritance of ability to set seed under bag could be postulated from the distributions of plants in the I_1 families.

Comparisons of parent with inbred progeny showed a significant reduction accompanying inbreeding in number of seeds set with open-pollination. The parent-progeny correlation coefficient for this character was statistically significant ($r=0.493$, $D/F=44$).

Selfed seed set was expressed as percentage of open seed set to obtain a self-fertility value. The parental clones ranged from 0.8 to 54.5% and the differences among clones were statistically significant. The parent-progeny correlation coefficient was 0.677 which with 44 D/F is highly significant. The reduction in percentage seed set of inbreds as compared with their parental clones was not significant statistically.

Within the inbred families, vigor was not closely correlated with ability to set seed under bag.

LITERATURE CITED

1. BARTLETT, M. S., and HALDANE, J. B. S. The theory of inbreeding in autotetraploids. Jour. Gen., 29:175–180. 1934.
2. BEDDOWS, A. R. Seed setting and flowering in various grasses. Welsh Plant Breeding Sta. Bul., Series H, No. 12:5–99. 1931.
3. FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 6. 1936.

4. FRANDSEN, H. N. Die Befruchtungsverhältnisse bei Gras und Klee in ihrer Beziehung zur Züchtung. Zeitschr. fur Pflanzenzüchtung, 5:1–30. 1917.
5. HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co., Inc. Ed. 2. 1927.
6. MÜNTZING, A. Quadrivalent formation and aneuploidy in *Dactylis glomerata*. Bot. Not., 1933:198–205. 1935.
7. ————. The effects of chromosomal variation in *Dactylis*. Hereditas, 23:113–235. 1937.
8. MYERS, W. M. Tetrasomic inheritance in *Dactylis glomerata*. Genetics, 25: 126. 1940. (Abstract)
9. ————. Genetical consequences of chromosomal behavior in orchard grass, *Dactylis glomerata*. Jour. Amer. Soc. Agron., 33:893–900. 1941.
10. ————. Analysis of non-heritable variations in ability to set seed under bag among plants of *Dactylis glomerata* L. Jour. Amer. Soc. Agron. (In press.)
11. ————, and HILL, HELEN D. The association and behavior of chromosomes in autotetraploid grasses. Genetics, 25:129. 1940. (Abstract)
12. ————, ————. Studies of chromosomal association and behavior and the occurrence of aneuploidy in autotetraploid grass species, orchard grass, tall oat grass, and crested wheatgrass. Bot. Gaz., 102:236–255. 1940.
13. ————, ————. Variations in meiotic behavior among plants of the autotetraploid *Dactylis glomerata*. Genetics, 26:162. 1941. (Abstract)
14. NILSSON, FREDRIK. Studies in fertility and inbreeding in some herbage grasses. Hereditas, 19:1–162. 1933.
15. SCHULTZ, H. K. A study of methods of breeding orchard grass (*Dactylis glomerata* L.). Jour. Amer. Soc. Agron., 33:546–558. 1941.
16. SMITH, D. C. Controlled pollination studies in grasses. (In manuscript.)
17. STAPLEDON, R. G. Self- and cross-fertility and vigor in Cocksfoot grass (*Dactylis glomerata* L.). Welsh Plant Breeding Sta. Bul., Ser. H, No. 12:161–180. 1931.
18. TROLL, HANS-JÜRGEN. Untersuchungen über Selbststerilität und Selbstfertilität bei Gräsern. Zeitschr. fur Züchtung, Reihe A, 16:105–136. 1931.
19. WOLFE, T. K., and KIPPS, M. S. Pollination studies with orchard grass. Jour. Amer. Soc. Agron., 17:748–752. 1925.

SURVIVAL OF BARLEY AND WHEAT VARIETIES IN MIXTURES[1]

C. A. SUNESON AND G. A. WIEBE[2]

ALTHOUGH admixtures in grain varieties are a bane to many agronomists, very little critical study of grain mixtures has been undertaken. Data already available (3)[3] suggest that the yields of varieties in mixed stands may not be correlated with those from the same varieties grown separately. This fact has a direct application to the bulked population method of breeding. Advocates of that method commonly assume that the forces of natural selection which favor the perpetuation of plants that are best fitted to survive the hybrid mixture will likewise sort out the types that will yield best when grown alone. Doubtless this assumption is correct when the undesired types are being eliminated by cold, disease, or other serious adverse factors, but in the absence of such factors valuable material is likely to be lost as a result of competition.

REVIEW OF LITERATURE

Competition between cereal plants has been studied from various angles. Cardon (1) has shown that grain crop mixtures under irrigated conditions in Montana produce smaller grain or forage yields than when the same crops are grown separately. The importance of rapid early growth in competitive stands of weeds and cereals has been emphasized by Pavlychenko (6). In his experiments wild oats were noticeably more aggressive and damaging in wheat than in the barley which had a more rapid early growth. Klages (4) found that early aggressive growth favored barley in mixtures with oats.

Competition between plants of the same crop and variety, irregularly spaced, has been studied by a number of workers, including Smith (7), who has shown that stand irregularities occurring in mechanically sown fields usually are adequately compensated by differences in tillering, growth, and yield of the individual plants.

Klages (4) reported yields for three stem rust susceptible wheat varieties grown in individual mixtures of different percentage composition with the stem rust resistant variety Mindum in a single season when stem rust was severe. The yields of Mindum in the various mixtures were in direct relationship to the stem rust damage to the susceptible varieties. Barley variety mixtures were tested extensively by Harlan and Martini (3). In experiments with a mixture of 11 varieties of barley grown for 4 to 12 years at 10 stations, they found evidence of early aggressiveness and increasing dominance of the local commercial type at certain stations, particularly Moro, Ore., and Moccasin, Mont. However, at Ithaca, N. Y., and St. Paul, Minn., the locally grown commercial variety in the mixture was depressed and varieties not grown in those localities dominated the mixture after a time. Parallel yield comparisons in pure culture of all varieties that comprised the mixture were not included.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the California Agricultural Experiment Station, cooperating. Received for publication July 18, 1942.

[2]Agronomists, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]Reference by number is to "Literature Cited", p. 1056.

Laude and Swanson (5) reported cumulative changes in mixtures of Kanred with Harvest Queen and with Currell at two locations over a 9-year period. Kanred, the better adapted variety, dominated all mixtures after 9 years. This was attributed to survival of more Kanred plants in competition and to production of more seeds per plant.

Frankel (2) mixed the high-yielding, but poor quality, wheat variety Tuscan with certain hybrid strains derived from it which were inferior in yield but of superior quality. The Tuscan variety yielded better in mixed than in pure stands, whereas the hybrid strains yielded less. The yields of the mixtures corresponded to the average yields of the components of the mixture when these were grown in pure stands.

MATERIALS AND METHODS

In the experiments at Davis, Calif., reported here, equal numbers of seeds of all varieties were mixed together for the initial seeding. The mixtures and pure varieties were grown annually in 1/50-acre plots seeded at rates varying from 55 to 80 pounds per acre. Yields of the mixed variety plots are not reported because the primary purpose of the experiment was to permit natural selection to operate while the stock was being perpetuated. The seed for planting the mixed variety plots was always taken from the previous year's mixed variety plot. Differential shattering of seed was never a factor in these experiments. Since cultivated alleys, varying in width during the course of the experiments, separated the 6-feet wide plots, competition on the borders was probably not fully comparable with that within the plots. Border effect seldom is very noticeable at this station, however. In the mixtures grown from 1933 to 1937, the varietal populations were determined from special independently grown, spaced plantings from seed harvested the previous season. In these special nursery rows, 500 or more plants were harvested and separated according to variety each year. From 1938 to 1941, 1,500 or more plants in a portion of the perpetuation plot were pulled before becoming over-ripe and were classified as to variety. The individual plants ordinarily were readily separable, though occasional close placement of identical seeds no doubt caused some error in determining the exact number of plants.

Three different mixtures of varieties that are grown commercially in California and are readily distinguishable because of differences in morphology, growth habit, or maturity, were grown in the experiments. One mixture consisting of four barley varieties was grown for 9 years. Another mixture to which a fifth variety was added was grown for 5 years, from 1937 to 1941. A mixture of five very dissimilar wheat varieties also was grown during this latter period.

EXPERIMENTAL RESULTS

The studies of mixed varieties show that competition between varieties of barley grown in mixed stands often caused results quite disproportionate from those expected on the basis of the yield performance of the individual varieties grown in pure stands (Tables 1 and 2). The previous conclusions were based on the assumption that the highest yielders are the best competitors in a mixture. The variety Vaughn usually excelled in yield, while Club Mariout usually gave the lowest yields in these experiments as well as in those conducted over a longer period at Davis. However, when grown in mixed stands, Vaughn proved to be a very poor competitor. None of the barley

SURVIVAL OF BARLEY AND WHEAT VARIETIES IN MIXTURES[1]

C. A. SUNESON AND G. A. WIEBE[2]

ALTHOUGH admixtures in grain varieties are a bane to many agronomists, very little critical study of grain mixtures has been undertaken. Data already available (3)[3] suggest that the yields of varieties in mixed stands may not be correlated with those from the same varieties grown separately. This fact has a direct application to the bulked population method of breeding. Advocates of that method commonly assume that the forces of natural selection which favor the perpetuation of plants that are best fitted to survive the hybrid mixture will likewise sort out the types that will yield best when grown alone. Doubtless this assumption is correct when the undesired types are being eliminated by cold, disease, or other serious adverse factors, but in the absence of such factors valuable material is likely to be lost as a result of competition.

REVIEW OF LITERATURE

Competition between cereal plants has been studied from various angles. Cardon (1) has shown that grain crop mixtures under irrigated conditions in Montana produce smaller grain or forage yields than when the same crops are grown separately. The importance of rapid early growth in competitive stands of weeds and cereals has been emphasized by Pavlychenko (6). In his experiments wild oats were noticeably more aggressive and damaging in wheat than in the barley which had a more rapid early growth. Klages (4) found that early aggressive growth favored barley in mixtures with oats.

Competition between plants of the same crop and variety, irregularly spaced, has been studied by a number of workers, including Smith (7), who has shown that stand irregularities occurring in mechanically sown fields usually are adequately compensated by differences in tillering, growth, and yield of the individual plants.

Klages (4) reported yields for three stem rust susceptible wheat varieties grown in individual mixtures of different percentage composition with the stem rust resistant variety Mindum in a single season when stem rust was severe. The yields of Mindum in the various mixtures were in direct relationship to the stem rust damage to the susceptible varieties. Barley variety mixtures were tested extensively by Harlan and Martini (3). In experiments with a mixture of 11 varieties of barley grown for 4 to 12 years at 10 stations, they found evidence of early aggressiveness and increasing dominance of the local commercial type at certain stations, particularly Moro, Ore., and Moccasin, Mont. However, at Ithaca, N. Y., and St. Paul, Minn., the locally grown commercial variety in the mixture was depressed and varieties not grown in those localities dominated the mixture after a time. Parallel yield comparisons in pure culture of all varieties that comprised the mixture were not included.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the California Agricultural Experiment Station, cooperating. Received for publication July 18, 1942.

[2]Agronomists, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]Reference by number is to "Literature Cited", p. 1056.

Laude and Swanson (5) reported cumulative changes in mixtures of Kanred with Harvest Queen and with Currell at two locations over a 9-year period. Kanred, the better adapted variety, dominated all mixtures after 9 years. This was attributed to survival of more Kanred plants in competition and to production of more seeds per plant.

Frankel (2) mixed the high-yielding, but poor quality, wheat variety Tuscan with certain hybrid strains derived from it which were inferior in yield but of superior quality. The Tuscan variety yielded better in mixed than in pure stands, whereas the hybrid strains yielded less. The yields of the mixtures corresponded to the average yields of the components of the mixture when these were grown in pure stands.

MATERIALS AND METHODS

In the experiments at Davis, Calif., reported here, equal numbers of seeds of all varieties were mixed together for the initial seeding. The mixtures and pure varieties were grown annually in 1/50-acre plots seeded at rates varying from 55 to 80 pounds per acre. Yields of the mixed variety plots are not reported because the primary purpose of the experiment was to permit natural selection to operate while the stock was being perpetuated. The seed for planting the mixed variety plots was always taken from the previous year's mixed variety plot. Differential shattering of seed was never a factor in these experiments. Since cultivated alleys, varying in width during the course of the experiments, separated the 6-feet wide plots, competition on the borders was probably not fully comparable with that within the plots. Border effect seldom is very noticeable at this station, however. In the mixtures grown from 1933 to 1937, the varietal populations were determined from special independently grown, spaced plantings from seed harvested the previous season. In these special nursery rows, 500 or more plants were harvested and separated according to variety each year. From 1938 to 1941, 1,500 or more plants in a portion of the perpetuation plot were pulled before becoming over-ripe and were classified as to variety. The individual plants ordinarily were readily separable, though occasional close placement of identical seeds no doubt caused some error in determining the exact number of plants.

Three different mixtures of varieties that are grown commercially in California and are readily distinguishable because of differences in morphology, growth habit, or maturity, were grown in the experiments. One mixture consisting of four barley varieties was grown for 9 years. Another mixture to which a fifth variety was added was grown for 5 years, from 1937 to 1941. A mixture of five very dissimilar wheat varieties also was grown during this latter period.

EXPERIMENTAL RESULTS

The studies of mixed varieties show that competition between varieties of barley grown in mixed stands often caused results quite disproportionate from those expected on the basis of the yield performance of the individual varieties grown in pure stands (Tables 1 and 2). The previous conclusions were based on the assumption that the highest yielders are the best competitors in a mixture. The variety Vaughn usually excelled in yield, while Club Mariout usually gave the lowest yields in these experiments as well as in those conducted over a longer period at Davis. However, when grown in mixed stands, Vaughn proved to be a very poor competitor. None of the barley

varieties used in these studies was widely different from the others in early growth, height, or maturity.

TABLE 1.—*Yields of varieties of barley and wheat grown separately in five 1/50-acre plots at Davis, Calif., 1933 to 1940.*

Variety	C.I. No.	Annual yields in bushels per acre*								Percentage of total yield (8-year av.)
		1933	1934	1935	1936	1937	1938	1939	1940	
					Barley					
Vaughn	1367	87.5	88.5	121.5	101.5	66.9	69.4	40.2	56.6	27.0
Atlas	4118	92.2	81.7	91.1	92.9	69.8	66.2	36.6	55.6	25.1
Hero	4602	81.0	81.7	95.0	83.6	66.4	61.0	39.7	53.5	24.0
Club Mariout	261	87.5	80.6	103.5	82.5	66.2	54.3	38.7	46.1	23.9
Stewart	6112	92.5	81.3	75.3	51.5	67.6	51.4	—	—	—
					Wheat					
Poso	8891	50.4	46.3	65.7	57.8	40.9	51.1	26.3	41.3	23.2
Ramona	8241–1	42.8	53.3	72.4	29.5	42.8	55.1	24.9	28.6	21.4
White Federation	4981	41.4	44.2	62.3	46.7	40.1	47.2	25.8	33.1	20.8
Baart	1697	48.8	37.7	55.1	35.8	36.6	38.3	24.2	44.7	19.7
Pacific Bluestem	4067	43.3	22.2	41.2	22.3	34.2	29.8	20.6	29.8	14.9

*Estimates of error for these mean yields have ranged from 1.8 to 3.7 bushels for barleys and 1.1 to 3.9 bushels for wheats.

Similar, though even more rapid, expressions of dominance in competition occurred in a mixture of five varieties of wheat, as shown also in Tables 1 and 2. Varieties of wheat having wide growth differences were seeded in this mixture, the extreme range being about 30 days in maturity, 15 inches in plant height, and 10 grams per 1,000-kernel weight. Dominance in the mixture showed relationships very different from the yielding ability of the varieties grown in pure stands, although the highest yielding wheat variety based upon an 8-year average also was most abundant in the mixture.

The reasons for the observed disparities are not obvious. The poor competitors often were really good varieties. Vaughn barley has become commercially important in California and Arizona by replacing, in part, the older varieties, Atlas and Club Mariout. Similarly, Ramona has been widely accepted in California displacing White Federation, Baart, or Pacific Bluestem in various localities.

Competition during the seedling stage was not particularly evident in the experiments at Davis, although other workers have considered this factor to be important. Barley and wheat are generally sown in California during November and December. The cool, midwinter temperatures and abundant moisture are conducive to slow growth and an extended seedling stage. Under these conditions, when sown at rates used in these studies, seedling mortality is not of consequence for even plants with chlorophyll deficiencies survive well, although they ultimately yield poorly. From the seedling stage to the jointing stage, Atlas appears to grow the most rapidly and Vaughn the slowest

TABLE 2.—*Proportion of each variety in varietal mixtures of barley or wheat grown at Davis, Calif., from successive seeding of mixtures originally containing equal numbers of seeds of each variety.*

Variety	Percentage of plants of each variety in mixture*								
	1933	1934	1935	1936	1937	1938	1939	1940	1941
Barley Mixture									
Atlas	25.4	38.1	47.4	42.8	49.2	54.4	47.7	63.2	65.5
Club Mariout	24.7	23.4	18.6	22.7	24.3	20.1	27.6	17.3	18.8
Hero	24.7	20.5	15.9	12.5	12.2	9.2	13.7	8.3	7.7
Vaughn	25.2	18.0	18.1	19.9	14.3	16.2	11.1	11.3	7.5
Barley Mixture									
Atlas	—	—	—	—	21.4	18.4	17.5	25.4	31.6
Club Mariout	—	—	—	—	17.5	21.6	26.8	26.6	31.7
Hero	—	—	—	—	22.2	22.3	27.5	25.9	24.1
Vaughn	—	—	—	—	19.4	20.0	15.7	15.0	9.1
Stewart	—	—	—	—	19.5	17.7	12.5	7.0	2.8
Wheat Mixture									
Poso	—	—	—	—	21.5	36.2	39.6	40.1	40.0
Baart	—	—	—	—	20.8	20.4	24.0	20.6	28.1
Pacific Bluestem	—	—	—	—	17.7	16.9	18.0	13.3	13.5
White Federation	—	—	—	—	20.4	16.4	11.9	18.8	13.4
Ramona	—	—	—	—	19.6	10.0	6.3	7.1	5.0

*Disparity from 100% total represents other varieties or natural hybrids.

for the barley varieties, but Ramona is the fastest growing wheat at this stage, followed by White Federation. Atlas barley and Ramona wheat are the most disease-susceptible varieties in the respective mixtures, Hero barley and Baart wheat produce the largest seeds, and Vaughn barley and Poso wheat produce the smallest seeds among the varieties involved. It is thus apparent that the reactions in these mixtures are very complex. The results point to a limitation in the bulked hybrid population method of breeding.

Segregates having yield and growth characteristics similar to those of Vaughn barley and Ramona wheat would seldom be recovered from advanced generation cultures of bulked hybrids.

SUMMARY

The relative yield of a variety is not necessarily a criterion of its ability to survive in competition with other varieties grown in mixtures in the same locality. The high-yielding and rather widely adapted varieties of Vaughn barley and Ramona wheat were poor competitors in mixtures with other varieties having slightly lower individual yields. The reasons for the disparity between individual and competitive yields are obscure. The behavior of certain varieties in mixtures suggests a decided limitation for the success of the bulked population method of breeding when populations are carried into advanced generations.

LITERATURE CITED

1. CARDON, P. V. Grain mixtures and root crops under irrigation. Mont. Agr. Exp. Sta. Bul. 143. 1921.
2. FRANKEL, O. H. Analytical yield investigations on New Zealand wheat. IV. Blending varieties of wheat. Jour. Agr. Sci., 29:249–261. 1939.
3. HARLAN, H. V., and MARTINI, M. L. The effect of natural selection in a mixture of barley varieties. Jour. Agr. Res., 57:189–199. 1938.
4. KLAGES, K. H. Changes in the proportions of the components of seeded and harvested cereal mixtures in abnormal seasons. Jour. Amer. Soc. Agron., 28:935–940. 1936.
5. LAUDE, H. H., and SWANSON, A. F. Natural selection in varietal mixtures of winter wheat. Jour. Amer. Soc. Agron., 34:270–274. 1942.
6. PAVLYCHENKO, T. K. Quantitative study of the entire root system of weed and crop plants under field conditions. Ecology, 18:62–79. 1937.
7. SMITH, H. F. The variability of plant density in fields of wheat and its effect on yield. Coun. Sci. Ind. Res. (Australia) Bul. 109. 1937.

NOTES

CRIMSON CLOVER IN THE COASTAL PLAIN OF THE SOUTHEAST[1]

FAILURE to obtain good stands and growth of crimson clover on Coastal Plain soils has been generally experienced. Recent experiments dealing with the factors of seed source, seedbed preparation, companion crop, fertilization, and inoculation have disclosed weaknesses of past prodecures. More specific consideration of these factors is presented as suggestions for reducing the failures and increasing the use of crimson clover as a winter cover, grazing, and hay crop in this section. Many of these suggestions also have application to other winter annual clovers and legumes.

SEED SOURCE

One of the weaknesses of crimson clover as a volunteer crop for grazing or winter cover is the rapid germination of most of the seed soon after it has shattered in early summer. The seedling plants die as a result of short periods of drought under high temperatures, and in some cases scalding, and no volunteer stand is established in the fall. However, several hard-seeded strains that volunteer to a good stand in the fall have been identified and tested. These strains have developed apparently through natural survival over many years and generations under grazing and the balk system of utilizing cover crops.

Germination tests on one of these strains conducted at different temperatures and intervals over a period of 2 years have shown that this strain contains over twice the number of hard seed as common crimson clover. If crimson clover is harvested for hay, this hard-seeded characteristic is not a factor in stand re-establishment since seed is not produced if the crop is cut for maximum hay yield. Furthermore, it is not known how long the hard seed will remain in the soil before germination.

SEEDBED PREPARATION AND COMPANION CROP

A firm seedbed is a well-known preprequisite in obtaining good stands, but frequently this factor has not been given sufficient emphasis. As has been shown with several other winter clovers, a closely clipped or grazed Bermuda grass provides an excellent seedbed. The short sod permits sufficient light necessary for germination and growth but at the same time affords protection for the inoculation and the seedling plants. While good stands may be obtained by broadcasting the seed on the surface, shallow drilling places the seed under more favorable conditions and a more complete stand is obtained with less seed.

FERILIZATION

Under most conditions fertilizer should be applied liberally in order

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture and the Georgia Coastal Plains Experiment Station, Tifton, Ga., cooperating.

to establish a good stand of crimson clover. Depending upon the character of the soil and fertilizer applications on the preceding crops, as much as 500 pounds per acre of a 4–8–8 or similar fertilizer may be required. Three to 400 pounds of 20% superphosphate or its equivalent and 100 pounds of potash per acre may be sufficient. It is also desirable to apply stable manure when available for in addition to its fertilizing value it protects the inoculation bacteria. Once the clover is successfully established, mineral fertilization may be necessary only every second or third year.

INOCULATION

A lack of efficient inoculation is one of the principal reasons for failures. (See Fig. 1.) Too frequently the seed is inoculated and planted without obtaining successful nodule formation. When hot, dry weather occurs at seeding time a second or even a third inoculation has proved to be beneficial. These supplemental inoculations may be done by thoroughly mixing artificial culture sufficient for a bushel of seed with 40 to 60 pounds of either moistened cottonseed meal, sand, or soil or a mixture of these. This mixture should be broadcast over an area of an acre, during cloudy, rainy weather only, 10 days to 2

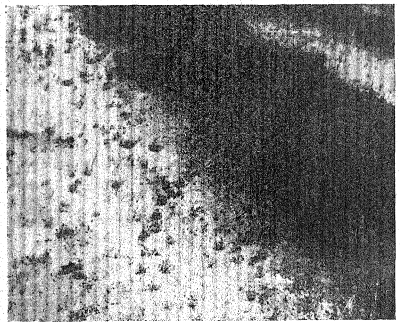


FIG. 1.—Growth of crimson clover resulting from sowing inoculated seed across Bermuda grass plots and adjacent alleys in the fall of 1941. Eight hundred fifty pounds of 3–10–6 fertilizer were applied at time of seeding. On left, alley way showing stunted, uninoculated plants. On right, inoculated thrifty crimson clover with Bermuda grass. Photograph taken April 19, 1942.

weeks after the seed is planted or when the seed is beginning to germinate. If the weather turns out to be unfavorable after the second inoculation a third attempted is recommmended. Crimson clover planted on the same soil year after year tends to grow better. This is probably the result of more complete inoculation.

The above requirements and procedures may appear expensive and tedious, but on Tifton sandy loam soils at the Georgia Coastal Plains Experiment Station a combination of crimson clover and the new hay type Bermuda grass has given four cuttings of hay per season (one clover and three grass cuttings), totaling 3 to 4 tons of hay per acre. Futhermore, it appears that this combination will reduce the need for renovating the Bermuda grass sod as frequently as would otherwise be required.—J. L. STEPHENS and E. A. HOLLOWELL, *Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

CASSIA TORA, A LEGUME NOT PRODUCING NODULES

THE development of nodules on roots of legumes is apparently not peculiar to all species. This was brought out by Leonard[1] and by Allen and Allen[2] with special reference to the genus *Cassia*. The author reported that under no known circumstances have nodules been found on *Cassia tora* L. However, Parks[3], reporting on this legume among others states, "It bears as many nodules as any cultivated legume". This statement has brought inquiries relative to the bacterial nitrogen-fixing status of *C. tora*.

While one cannot definitely say nodules will or will not be found under any circumstances on this legume it would seem, if they occur at all, that they should be observed in places in the southeastern states where the plant abounds. Numerous recent observations in this territory have failed to bring to light any data to confirm the statement of Dr. Parks. In correspondence with Dr. Parks it is indicated that his observations were made in the Sabine region of Texas. This section is considerably west of the area in which the author examined roots of *C. tora*. In order to obtain material from the Sabine region, Dr. M. B. Morrow was asked to get specimens for examination. At her suggestion, Prof. S. R. Warner, Sam Houston Teachers' College, Huntsville, Texas, kindly collected and forwarded liberal samples in 1941. Some of these exhibited galls, but none had the external appearance, and some examined internally did not have the characteristics of leguminous plant nodules.

Some of the galls were given to Mr. E. A. Siegler of the Bureau of Plant Industry who kindly made determinations for *Phytomona tumefaciens* (Smith and Townsend) Bergey, *et al.* His tests were negative, thereby showing the galls were not the result of an infection with this organism. Other material from the same lot was examined

[1]LEONARD, LEWIS T. Lack of nodule-formation in a sub-family of the Leguminosae. Soil Sci., 20:165–167. 1925.

[2]ALLEN, O. N., and ALLEN, E. K. Plants in the sub-family Caesalpinioideae observed to be lacking in nodules. Soil Sci., 42:87–91. 1936.

[3]PARKS, H. B. Valuable plants native to Texas. Tex. Agr. Exp. Sta. Bul. 551. 1937.

through the courtesy of Dr. E. Steiner for nematode infestation. Root knot nematodes were present in small numbers, indicating the galls were probably initiated by them.

Allen and Allen[4] failed to find nitrogen-fixing bacteria in the tissues of *C. tora;* and although Leonard and Reed[5] used this species in comparative green manuring tests with apparent success in the matter of dry matter production, no evidence of biological nitrogen fixation was brought out.

It would seem that Dr. Parks' observations may be explained as follows: (1) A special condition for *C. tora* was located which others have not found; (2) observations were made on legume roots not those of *C. tora;* (3) nematode galls were mistaken for bacterial nitrogen-fixing nodules commonly found on crop legumes. From the information presented here the latter condition is the most plausible. Until more positive information is available, it must be concluded that symbiosis evidenced by nodule-formation is lacking in *C. tora.*—LEWIS T. LEONARD, *Division of Soil and Fertilizer Investigations, Research Center, Beltsville, Md.*

BOOK REVIEWS

FIELD CROPS

By Howard C. Rather. New York: McGraw-Hill Book Company, Inc., IX+454 pages, illus. 1942. $3.75.

ONE might wonder what could be added to the considerable number of excellent books in the agronomic field already available on this subject. The author of this book, who is head of the Farm Crops Division at Michigan State College and Experiment Station, states that the book is designed to furnish a broad survey of the field of agronomy for students entering this field and also to provide insight into agronomic problems for students majoring in closely related fields. It is intended as a first course and in many cases an only one for college students. It aims to cover comprehensively the theory and practice of crop production and land management. At the chapter ends are review questions and problems for the student and also suggestive references.

The 23 chapters deal with such general subjects as significance, classification, and improvement of field crops, relation to farm and soil management, and tillage. Specific attention is then paid to legumes, grasses, forage and silage crops, pastures, and grains. Potatoes, sugar crops, cotton, and tobacco are also covered. A short appendix is followed by a good index.

The book should certainly be given attention by teachers of agronomy who have courses of similar nature and the general student and practical worker along agronomic lines also will find much of value to interest them. (R. C. C.)

[4]ALLEN, E. K., and ALLEN, O. N. Attempts to demonstrate symbiotic nitrogen fixing bacteria within the tissues of *Cassia tora*. Amer. Jour. Bot., 20:79–84. 1933.

[5]LEONARD, LEWIS T., and REED, H. R. A comparison of some nodule forming and non-nodule forming legumes for green manuring. Soil Sci., 30:231–236. 1930.

THE PEATS OF NEW JERSEY AND THEIR UTILIZATION: PART A

By Selman A. Waksman. Bulletin 55 Geologic Series, Department of Conservation and Development, State of New Jersey, Trenton, N. J., in Cooperation with the Agricultural Experiment Station, Rutgers University. 155 pages, illus. 1942.

PRIOR to the outbreak of the war, the sale and use of peat in the United States had grown to large proportions. Most of this peat was supplied by Germany and the Scandinavian countries and comparatively little came from domestic sources. Since these importations have been cut off, a serious effort has been made in a number of states and in Canada to develop local sources of supply. This has created an active interest in our own peat deposits and this publication is in response to this interest.

Part A, here reviewed, deals with the nature and origin of peat, its composition, and utilization, while part B to follow will give the area and cross section of all the important peat deposits of New Jersey.

The bulletin is comprehensive, has a bibliography of 339 titles, and a subject index. The material is timely and it is hoped will stimulate similar surveys in other states of a hitherto neglected natural resource. (R. C. C.)

AGRONOMIC AFFAIRS

ORGANIZATION OF NATIONAL JOINT COMMITTEE ON NITROGEN UTILIZATION

AT the suggestion of Director W. H. Martin of the New Jersey Agricultural Experiment Station, the National Fertilizer Association invited the representatives of the following organizations to participate in a conference on post-war nitrogen utilization problems: American Society of Agronomy, the American Society for Horticultural Science, the Land-Grant College Association, the Tennessee Valley Authority, the U. S. Dept. of Agriculture, and the National Fertilizer Association. The conference was held in Washington September 23, with 18 in attendance. Dr. Richard Bradfield, President of the American Society of Agronomy, was elected chairman of the conference. The following statement indicates the action of the conference.

A STATEMENT CONCERNING THE PROPOSAL TO ORGANIZE A NATIONAL JOINT COMMITTEE ON NITROGEN UTILIZATION

THE PROBLEM

Following the present war the by-product and synthetic ammonia capacity of the United States will be approximately twice as great as the maximum consumption of ammonia for agricultural and industrial purposes prior to the war. This great increase in ammonia capacity may be at the disposal of agriculture in the post-war period. The proper utilization of this nitrogen presents an opportunity and a challenge to the agricultural scientists of this country.

THE NEED FOR THE JOINT COMMITTEE

Certainly, in any research program that may be undertaken, the public agricultural research agencies should be utilized and the work should be so planned and allocated as to attack many phases of the problem simultaneously without waste of effort. It is felt that these objectives can best be attained by enlisting the cooperation of the U. S. Department of Agriculture, the Association of Land-Grant Colleges and Universities, the American Society of Agronomy, the American Society for Horticultural Science, the Tennessee Valley Authority, and The National Fertilizer Association in setting up a joint committee. Through such a committee research workers in soils, plant breeding, plant production, fertilizer technology, and related fields could be brought together for exchange of ideas and planning of projects. Subcommittees and special committees could be appointed to handle details, with the National joint committee serving as the coordinating agency. The group attending the preliminary conference on September 23 voted unanimously in favor of organizing such a joint committee.

The National Joint Committee on Fertilizer Application, organized in 1925, has done outstanding work in its field and is still actively functioning. Its organization and methods of procedure could serve as a pattern in setting up the new committee.

OBJECTIVES

The objectives would be to plan and promote a well correlated program of research on nitrogen utilization in agriculture; to develop the fundamental information on which decisions would be based as to how the farmers in this country can utilize most effectively the large supplies of nitrogen fertilizers that will probably be available during the post-war period.

INVESTIGATIONS NEEDED

The following are typical lines of research that were suggested at the preliminary conference in Washington on September 23:

a. Determine the value of small grains and grasses plus commercial nitrogen for winter grazing, erosion control, and green manuring;

b. Study the utilization of nitrogen with crop residues and straw mulches in humid and semi-arid regions;

c. Determine the relative economy of commercial and legume nitrogen for crop production under a wide variety of cropping, soil and climatic conditions;

d. Measure crop increases produced by given quantities of nitrogen under a variety of conditions in order to set up more accurate standards of "returns from nitrogen" than have hitherto been available;

e. Study the problems of nutrient balance, crop quality and composition when heavy applications of nitrogen are applied, as for vegetables and fruit crops;

f. Study the utilization of nitrogen at varying levels of application for the production of feed crops, corn, small grains and pastures;
g. Study the utilization of nitrogen in forestry, as for the production of slash pine and for fine hardwoods;
h. Determine the relation of nitrogen use to biological problems, such as control of plant diseases and weeds;
i. Investigate the possibility of breeding crop plants for production at high levels, and, finally
j. Study the effects that may be expected from the use of greatly increased quantities of nitrogen fertilizers on the whole agricultural economy.

ORGANIZATION OF THE JOINT COMMITTEE

At the preliminary conference it was voted that each participating agency or organization should be represented on the joint committee by not to exceed *five* persons. These representatives should undoubtedly be appointed annually. The aid of additional scientists would be obtained through the appointment of subcommittees or special committees, to whom special tasks would be assigned.

CONFERENCE IN ST. LOUIS

In order to complete the organization of a joint committee on nitrogen utilization, a conference is being arranged and will be held in St. Louis on November 10th in connection with the annual meetings of the American Society of Agronomy and the Society of Soil Science. All interested persons are invited to attend and take part in the discussions. The conference will be held at the Statler Hotel beginning at 10 A.M. It is expected that official delegates will be appointed by all of the participating organizations and agencies by that date.

The above statement was prepared by the special committee authorized by the action taken at the preliminary conference on September 23rd consisting of the following persons:

R. M. Salter, *Chairman*	J. H. Gourley
F. E. Bear	F. W. Parker
Richard Bradfield	H. R. Smalley, *Secretary*

NEWS ITEMS

Doctor R. W. Cummings, Head of the Agronomy Department of the North Carolina State College, makes the following announcements concerning the personnel of the department:

Dr. E. R. Collins who has been Associate in Agronomy on the Station staff for 6 years is now in charge of Agronomy Extension, coordinating the research and extension work of the Department.

Dr. J. F. Lutz is in charge of soils teaching and also has assumed leadership of the new tobacco research program of the Department. In his work with tobacco, Dr. Lutz expects to cooperate closely with the work of the Bureau of Plant Industry, U. S. Dept. of Agriculture,

and the North Carolina Department of Agriculture which is under the supervision of Mr. E. G. Moss at the Oxford Tobacco Branch Experiment Station.

Dr. J. Fielding Reed accepted a joint position with the North Carolina Agricultural Experiment Station and the North Carolina Department of Agriculture June 1. He was associated with Dr. I. E. Miles in the Soil Testing Division of the State Department until Dr. Miles was called to the Army recently. In Dr. Miles' absence Dr. Reed is in charge of soil testing and will do research on soil testing methods with the Agricultural Experiment Station. He came to North Carolina from Louisiana State University where he was Assistant Professor of Agronomy.

Dr. W. E. Colwell was appointed Associate in Soils Research and Associate Professor of Agronomy September 1. He took his Bachelor's degree at the University of Nebraska, his Master's degree at the University of Idaho, and his Ph.D. degree at Cornell this past summer. Prior to going to Cornell 2 years ago he was Instructor in Soils at the University of Idaho for 3 years.

Dr. Walton C. Gregory has been appointed Assistant Agronomist and Assistant Professor of Agronomy, effective October 1. He is a cytogeneticist and for 2 years has been Assistant Professor of Biology at Tennessee Polytechnic Institute. He will teach plant breeding and assist Dr. P. H. Harvey in the expanded corn breeding program.

—A—

DOCTOR R. L. LOVVORN, in charge of forage crop investigations at the North Carolina Experiment Station received his Ph.D. degree at the University of Wisconsin in June.

—A—

J. C. HOGENSON, Extension Agronomist of the Utah Agricultural Extension Service, died on March 17 at the age of 67. Professor A. F. Bracken, Associate Professor of Agronomy, Utah State Agricultural College, has been appointed to fill the vacancy of Extension Agronomist.

—A—

PROFESSOR D. C. TINGEY, Associate Professor of Agronomy, Utah State Agricultural College, has been appointed Senior Agronomist with the U. S. Dept. of Agriculture, Bureau of Plant Industry. He will be connected with research on the production of quayule.

—A—

PROFESSOR BLISS CRANDALL, formerly Instructor in Farm Crops, Iowa State College, has been appointed Assistant Professor of Agronomy at the Utah State Agricultural College.

pressor starting switch P is energized, starting the refrigerating compressor. In this same circuit is the refrigerant pressure switch D which was previously referred to in Fig. 3. This switch closes upon a drop in refrigerant suction pressure, energizing the relay R to start the cooling coil blower.

COIL DEFROSTING CIRCUIT

One of the most important features of the equipment is the provision for automatic defrosting of the cooling coil. The defrosting circuit tracing through the lower contact of relay O in Fig. 6 consists of the refrigerant suction pressurestat F controlling the three-way solenoid air valve J. From the pressurestat F, a circuit to relay Q runs the blower during the defrosting cycle.

OPERATION OF THE APPARATUS

THE DEHUMIDIFYING CYCLE

In tracing the operation of the equipment, it might be less complicated to take up first the running or dehumidifying cycle. With the humidistat set for the desired humidity and the defrost cycle completed, let us assume that there is a rise in moisture content of the storage room. The humidistat circuit closes, causing the main relay O (Fig. 6) to close the upper contact circuit, starting the refrigerating compressor. As the cooling coil becomes colder, the refrigerant suction pressure drops. The suction pressurestat D is set to close the circuit to the blower as soon as the coil temperature has dropped sufficiently to freeze all free moisture on the surface of the cooling coil, thus preventing the circulation of a considerable quantity of moisture from the coil back to the storage room. While control D could be dispensed with by placing the blower starting switch in parallel with the compressor switch P, yet the advantage of the delayed starting of the blower adds materially to the efficiency of the system, especially when extremely low humidities are to be maintained.

After the blower starts, air is circulated from the room through the cooling unit, which lowers the air temperature below the necessary dew point, freezing out moisture on the coil surface. The principle involved in the lowering of the room humidity is the freezing of the moisture on the cold coil surfaces and the delivery of this cold, nearly saturated air, back into the room where it is warmed to the desired room temperature by means of the strip heaters. Since relative humidity is a function of the moisture content and the temperature of the air, the result is a decrease in the relative humidity in the storage room.

As the cold air from the coil enters the storage room, the thermostat turns on the strip heater to maintain the desired room temperature. The strip heat unit has been sufficient to hold the room at 70° F during the compressor running periods, since much of the cooling energy is absorbed as latent heat in the changing of water vapor into ice. The most efficient rate of air flow across the coil was determined experimentally by observing the refrigerant suction pressure and the

rate of moisture removal from the storage room air. With the equipment set to maintain 16% relative humidity at 70° F, an air velocity through the coil of somewhat under 200 C.F.M. and a refrigerant temperature of -10° F (5 pounds Freon pressure) have been found satisfactory. This air flow may be regulated by varying the blower speed. If more air is passed over the coil, the leaving air temperature will be proportionately higher, thus freezing out less moisture while increasing the energy devoted to cooling of the air, making more electrical reheat necessary. The most economical operating conditions were found by studying the operating cycle of the equipment under different seasonal conditions.

THE COIL DEFROSTING CYCLE

Under normal operating conditions the dehumidifying cycle will last 10 to 20 minutes before the humidistat becomes satisfied and opens the circuit controlling relay O (Fig. 6), stopping the compressor and starting the defrosting cycle. The dropping of this relay establishes the defrosting circuit from O through the suction pressurestat F to operate the three-way solenoid valve J. This air valve admits air to the branch line (Fig. 5) and lifts the dampers, cutting off circulation from the cooling unit to the storage room and permitting circulation of outside air through the coil. Much of the success of the installation depends upon the action of these dampers in preventing warm saturated air from re-entering the storage room during the defrosting cycle. The same circuit that energizes the three-way valve J also runs the blower through relay Q (Fig. 6).

The defrost cycle continues until all ice is removed from the coil surfaces. The interrelation between suction pressure of a refrigerant and the coil temperature is made use of in controlling the length of the defrost cycle. The pressurestat F is set to break contact after the pressure has risen to 45 or 50 pounds. This latter point was determined experimentally by watching the point at which the coil was entirely defrosted and the condensate had practically ceased to flow from the drain trap. When the defrost is completed the circuit is broken through pressurestat F, thus de-energizing the three-way valve and stopping the blower. The dampers then return to the running position as air drains from the branch line through the vent port of the three-way valve (Fig. 5). Thus the dampers return to their normal position, the blower is stopped, and the equipment remains idle until the humidistat again calls for dehumidification.

One of the important instruments in insuring the complete defrosting between each run is the air switch or pressurestat marked L and shown in the wiring diagram as the switch immediately above the humidistat and wired in series with it. The function of the switch which is actuated by the branch line air that raises the dampers is to open the humidistat circuit when the defrost cycle starts, making it impossible for the humidistat to close the main control relay O until all ice is off the coil and the dampers are returned to their normal position. This interlocking air switch is superior to any type of clock or other time delay device that could be used, as it holds the humidistat inoperative only until defrost is complete, a period that varies

with the amount of ice to be removed from the coil and temperature of the outside air that is circulating through the coil.

The normal operation of the equipment described presupposes that the compressor and cooling coil have sufficient capacity with respect to the storage room to remove sufficient moisture during each compressor run to satisfy the humidistat before the coil becomes too heavily frosted. This is necessary as the initiation of the coil defrosting cycle is dependent upon the action of the humidistat. No difficulty has been experienced with this equipment during extreme summer weather at Urbana, Ill., with high temperatures and humidities. However, the precaution must be taken when starting up the equipment in humid weather, or after loading the room with moist samples, to trip the humidistat circuit air switch by hand after the first large amount of moisture has been removed by the coil (usually 20 or 30 minutes run is sufficient). After that the moisture removal is gradual enough so the dehumidifying and defrosting cycles proceed automatically.

Temperatures between 60° F and 80° F, with relative humidities between 14% and 60%, have been maintained in the room. By proper location of the thermostat and humidistat, control has been held within $\pm 2\%$ of the selected humidity and $\pm 1°$ or $2°$ of the selected temperature.

SUMMARY

In an effort to obtain more comparable samples of soybean seed held for chemical analysis, controlled low-humidity storage conditions are being utilized. Such low-humidity storage would be of value to the plant breeder in preserving the viability of seed stocks over an extended period.

Equipment for maintaining constant low humidity in a laboratory seed storage room is described. This equipment is capable of maintaining 16% relative humidity and 70° F temperature in an insulated room used for the year around storage of soybean seed. A refrigerating compressor and cooling coil are used to remove moisture from the air while electrical heat is used to reheat the air to the desired temperature.

A unique feature of the equipment is the provision for rapidly and automatically defrosting the cooling coil, a feature of paramount necessity when operating conditions require a coil temperature considerably below the freezing point of water. Defrosting of the coil is accomplished by a system of simple dampers that isolate the room from the equipment during the defrost period, while allowing warm outside air to flow through the coil to accelerate the removal of ice from the coil surfaces. The circuit for automatically controlling the defrost cycle to insure complete removal of the ice from the coil is described. Another feature that improves the economy of operation of the system is the pressurestat in the blower control circuit that delays the starting of the blower during the running cycle until free water on the coil is frozen, thus preventing this water on the coil from being evaporated and carried back into the storage room at the start of each compressor run.

LOCATION OF GLOSSY AND YELLOW SEEDLINGS IN TWO LINKAGE GROUPS[1]

D. W. ROBERTSON AND O. H. COLEMAN[2]

THIS paper presents the results of studies on two additional factor pairs in barley together with their linkage relationships. A recent review by Robertson, Wiebe, and Immer (11)[3] gives a brief description of the various characters which have been located in the different linkage groups in barley.

MATERIAL AND METHODS

The parent varieties used in this study were Glossy 2 and Faust I. Glossy 2 is a six-rowed, white-glumed, naked barley with long-haired rachilla and glossy foliage. The original plant was obtained from Dr. L. J. Stadler of the University of Missouri. It was a homozygous recessive selection made from the variety Himalaya which had been treated with X-ray. The glossy character is similar to that found in maize (2). It carries through to maturity, however, being inherited as a simple recessive to normal. The plants are somewhat weaker than normal plants. Because of the difficulty of obtaining seed sets when Glossy 2 plants are used as female parents, all crosses in the studies were made using Glossy 2 plants as the pollen parent.

Faust I is a six-rowed, white-glumed, naked hooded barley with long-haired rachilla and blue aleurone. It is heterozygous for the yellow seedling factor pair (Yy^x). The seedling color is chartreuse yellow (8). The seedlings die when they are about 2 weeks old. Because of the difficulty of getting seed sets when Faust I is used as the female parent, it was used as the pollen parent in the crosses studied.

Some 16 contrasting characters were used in studying the linkage relationships of normal vs. glossy plants (Gl_2gl_2) and green vs. xantha seedlings (Yy^x).[4]

The following varieties were used as parents: *H. dis. nigrinudum*,[5] *H. def. nudideficiens*, Trebi I, Trebi IV, Colsess I, Colsess IV, Colsess V, Coast II, Coast III, Minnesota 84-7, and Minnesota 72-8.

The genetic constitution of Glossy 2 is as follows: vv, FF, YY, bb, A_tA_t, nn, $A_{c2}A_{c2}$, gl_2gl_2, kk, II, SS, A_nA_n, Y_cY_c, and F_cF_c. Faust I, besides containing the factor pair (Yy^x) in the heterozygous condition, has the following genetic constitution: vv, FF, OrOr, bb, nn, KK, SS, A_nA_n, A_cA_c, Y_cY_c, and F_cF_c.

In studying the interaction of factor pairs for chlorophyll-defective seedlings, plants heterozygous for the chlorophyll-defective factor pairs were used as parents.

Since F_2 genotypes were found by Immer (4, 5,) and Mather (7) to furnish more information than F_2 phenotypes, they were used in determining linkage values.

[1]Contribution from the Department of Agronomy, Colorado State College, Fort Collins, Colo. Authorized by the Director of the Colorado Agricultural Experiment Station for publication as Scientific Journal Series Article No. 148. Received for publication July 6, 1942.

[2]Agronomist and Assistant Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 1034.

[4]Throughout the paper, the nomenclature suggested by Robertson, et al. (11) is used.

[5]*H. dis. nigrinudum* will be referred to as Nigrinudum I and *H. def. nudideficiens* as nudideficiens in this paper.

Linkage values from F_2 phenotypic ratios were determined from formulae developed by Immer (4) or by the use of Collins' formula (1) when phenotypic classes had to be grouped (9:3:4 ratios).

CHARACTERS SHOWING LINKAGE

From these studies the factor pair (Yy^x) for green vs. yellow seedlings in Faust I was found to be located in group I. Table 1 gives the observed numbers and calculated ratios for independent inheritance for various factor pairs located in group I and the factor pair (Yy^x). A poor fit to the calculated ratio for independence of the factor pairs (Vv), (Ff), (Or or), and (Yy^x) is found for both F_2 phenotypic and genotypic ratios. A good fit of the factor pair (Vv) for non-six-row vs. six-row and the seedling factor pair (Yy^x) with 31% crossing over is obtained. The factor pair (Ff) for green vs. chlorina seedlings was found to be closely linked to the factor pair (Yy^x). The best fit was obtained to a calculated ratio with 1.7% crossing over. The factor pair green vs. orange seedlings previously located in group I (10) was found to be linked to the factor pair (Yy^x) with 15% crossing over (Table 2).

The factor pair (Yy) for green vs. virescent seedlings, previously located in group I with recombination values of 0.81% between (Yy) and (Ff), 13.36% between (Yy) and (Or or), and 31.27% between (Yy) and (Vv), was found to be a multiple allele of the factor pair (Yy^x). A ratio of 40 green to 11 virescent was found in F_1 of crosses between Minnesota 72-8 and Faust I. As was previously stated, Minnesota 72-8 was used as the female parent. All of the F_1 plants were hooded, indicating that they were hybrids, since the female parent was awned.

The types of plants obtained in F_2 are shown in Table 3.

The observed ratio fits very closely to the 1:1:1:1 ratio expected for F_1 genotypes when plants of the genetic constitution Yy and Yy^x are crossed. The results indicate that the factor pairs Yy and Yy^x are multiple alleles. The varieties which carry the alleles in the heterozygous condition were obtained from two widely separated sources. Minnesota 72-8 is a strain originally obtained in the heterozygous condition by the Minnesota station from C. Hallquist in Sweden. Faust I was originally found in a plot of Faust grown at the Colorado Agricultural Experiment Station. Faust is a selection from Himalaya, an awned, hull-less variety.

From these studies the following linear arrangement is suggested, Vv–Y, y^x, y–Ff–Or or. This agrees with previous findings for the factor pair (Yy).

Glossy 2 was found to be linked with two factor pairs found in group IV (Table 4). A good fit to a calculated crossover value of 25% between hoods vs. awns and normal vs. glossy plant was found in a cross of Colsess IV and Glossy 2. The factor pair (Ii) for intermedium vs. non-intermedium previously described by Harlan and Hayes (3), Robertson (9), and Leonard (6) is linked with (Kk), the factor pair for hoods vs. awns with 15.1% crossing over. A good fit to a calculated crossover value of 28% was obtained for the factor pairs (Gl_2gl_2) and (Ii).

TABLE I.—*Fit of F_2 phenotypic and F_2 genotypic classes to a calculated 9:3:4 and 1:2:2:4:1:2 ratio.*

Cross	Genotype studied		Phenotypes				P
			AB	Ab	aB	ab	
Nigrinudum I × Faust I	$VvYy^x$						
Observed number			645.0	138.0	—	254.0	
Calculated 9:3:4 ratio			583.31	194.44	—	259.25	0.01
Minn. 84-7 × Faust I	$FfYy^x$						
Observed number			1245.0	670.0	—	571.0	
Calculated 9:3:4 ratio			1398.38	466.12	—	621.5	Very small
Trebi IV × Faust I	$OrorYy^x$						
Observed number			479.0	242.0	—	237.0	
Calculated 9:3:4 ratio			538.88	179.62	—	239.5	Very small
			F_2 Genotypes				
Nigrinudum I × Faust I	$VVYY^x$	$VVYy^x$	$VvYY^x$	$VvYy^x$	$vvYY^x$	$vvYy^x$	
Observed number	131.0	103.0	99.0	304.0	20.0	114.0	
Calculated 1:2:2:4:1:2 ratio	64.25	128.5	128.5	257.0	64.25	128.5	Very small
Minn. 84-7 × Faust I	$FFYY^x$	$FFYy^x$	$FfYY^x$	$FfYy^x$	$ffYY^x$	$ffYy^x$	
Observed number	0.0	14.0	21.0	998.0	425.0	15.0	
Calculated 1:2:2:4:1:2 ratio	122.75	245.5	245.5	491.0	122.75	245.5	Very small
Trebi IV × Faust I	$OrOrYY^x$	$OrOrYy^x$	$OrorYY^x$	$OrorYy^x$			
Observed number	9.0	36.0	25.0	213.0	—	—	
Calculated 1:2:2:4:1:2 ratio	31.44	62.89	62.89	125.78	—	—	Very small

TABLE 2.—*Fit of F_2 phenotypes and genotypes to ratios calculated for various crossover values.*

Cross	Genotype studied	Phenotypes					P
		AB	Ab	aB and ab			
Nigrinudum I × Faust I	$VvYy^x$						
Observed number	—	645.0	138.0	254.0			
Calculated with 31% C.O.		641.93	135.82	259.25			0.95–0.90
Minn. 84–7 × Faust I	$FfYy^x$						
Observed number		1245.0	670.0	571.0			
Calculated with 1.7% C.O.		1243.18	621.32	621.5			0.02–0.01
Trebi IV × Faust I	$OrorYy^x$						
Observed number		479.0	242.0	237.0			
Calculated with 15% C.O.		484.39	234.11	239.5			0.9–0.8
		F_2 Genotypes					
Nigrinudum I × Faust I	$VVYY^x$	$VVYy^x$	$VvYY^x$	$VvYy^x$	$vvYY^x$	$vvYy^x$	
Observed number	131.0	103.0	99.0	304.0	20.0	114.0	
Calculated with 31% C.O.	122.36	109.94	109.94	294.11	24.70	109.95	0.7–0.5
Minn. 84–7 × Faust I	$FFYY^x$	$FFYy^x$	$FfYY^x$	$FfYy^x$	$ffYY^x$	$ffYy^x$	
Observed number	0.0	14.0	21.0	998.0	425.0	15.0	
Calculated with 1.7% C.O.	0.14	16.41	16.41	949.20	474.45	16.41	0.1–0.05
Trebi IV × Faust I	$OrOrYY^x$	$OrOrYy^x$	$OrorYY^x$	$OrorYy^x$			
Observed number	9.0	36.0	25.0	213.0	—	—	
Calculated with 15% C.O.	3.15	35.68	35.68	208.49	—	—	0.01

TABLE 3.—*Genetic constitution of the F_1 plants from the cross Minnesota 72–8 × Faust I.*

	F_1 genotypes					
	YY^x	Yy^x	yY^x	yy^x	X^2	P
No. of plants	8	5	4	5	—	—
Calculated 1:1:1:1 ratio	5.5	5.5	5.5	5.5	1.6363	.9–.8

The indications from the foregoing data are that the linear order of the factor pairs on the chromosome are (Ii), (Kk), and (Gl_2gl_2). Further information with other factor pairs in this group, however, is necessary before definite conclusions can be drawn. Ingersoll,[6] in a preliminary study, found a crossover value in F_2 of 19% between Gl_2gl_2 and Kk.

CHARACTERS INDEPENDENTLY INHERITED

The factor pair (Yy^x) found in Faust I was found to be inherited independently of the following factor pairs: (Bb) group II, (Nn) group III, (Kk) group IV, (Ss) group V, (A_ca_c) and (A_na_n) group VI, and (F_cf_c) and (Y_cY_c) in group VII.

The factor pair (Gl_2gl_2) was found to be inherited independently of the following factor pairs found in six of the linkage groups of barley: I, (Vv), (Ff), and (Yy); II, (Bb) and (A_ta_t); III, (Nn) and ($A_{c2}a_{c2}$); V, (Ss); VI, (A_na_n); and VII, (F_cf_c) and (Y_cY_c).

SUMMARY

Two additional factor pairs are described. Glossy 2 (Gl_2gl_2) is a simple Mendelian factor pair for green vs. glossy plant. The entire plant is glossy. It was obtained by L. J. Stadler of the University of Missouri who selected it as homozygous recessive from Himalaya which had been treated with X-ray.

Faust I contains a factor pair (Yy^x) for green vs. yellow seedlings. The seedling character is inherited as a simple recessive. The color of the seedling is chartreuse yellow (Ridgeway, Plate XXXI).

The factor pair (Gl_2gl_2) is located in group IV. The order of the genes was (Ii), (Kk), and (Gl_2gl_2).

The factor pair (Yy^x) is an allele of (Yy), a factor pair for green vs. virescent seedling found in Minnesota 72–8. The gene for this factor pair is located in group I. The order of the genes in the chromosome is (Vv), (Yy^x), (Ff), and (Or or).

The factor pair (Gl_2gl_2) was found to be inherited independently of factor pairs located in groups I, II, III, V, VI, and VII.

The factor pair (Yy^x) was found to be inherited independently of factor pairs located in groups II, III, IV, V, VI, and VII.

[6]Correspondence with Dr. E. R. Sears, Columbia, Mo.

JOURNAL

OF THE

American Society of Agronomy

VOL. 34 DECEMBER, 1942 NO. 12

OUR JOB AHEAD[1]

RICHARD BRADFIELD[2]

THERE has been considerable discussion of the advisability of holding our annual meeting this year. Some saw the physical difficulties involved and favored cancellation. The majority, perplexed by the numerous new problems confronting them as a result of the war, felt even more keenly than normally the need to talk over their problems with their colleagues in other institutions. All felt that to justify a meeting at this time especial emphasis should be placed upon problems connected with the war. Such problems have been the dominant theme of our program.

Tonight, I shall exercise my prerogative as your President to speak to you about the job that lies ahead of us as agronomists in the post-war world. My remarks are based on the premise that the war will end eventually in a victory for the United Nations. I would not care to think about any other type of post-war world.

I think I can justify speaking about post-war problems in the midst of the war. This is a war of ideals. We need a clear conception of what we are fighting for, if we are to put our best efforts into the war. We need to express our objectives clearly so that the rest of the world can know what they are and can support us if they believe as we do. The problems of the post-war period will be just as difficult, possibly even more difficult, than those of the war. Internal dissention tends to disappear during a war. It will tend to rise again after the tension of war eases and we begin to consider the superficially less urgent problems of peace. The necessity of war was obvious after Pearl Harbor. The maladjustments of peace may fester for a generation before erupting. We won the last war but lost the peace. We must make this victory complete!

If the victory is to be complete and the peace a lasting peace, it is none too early for all of us to be thinking about it. It is well to have special post-war planning boards to work out details, but in our democracy, the final word is with the people. Our leaders will be helpless unless they have a clear mandate from the people. And finally, if these are not sufficient reasons for speaking about post-war

[1]Presidential address delivered at the annual meeting of the Society in St. Louis, Mo., November 12, 1942.

[2]Head, Department of Agronomy, Cornell University, Ithaca, New York.

problems in the midst of war, I shall confess that I am, by nature, an idealist, a day dreamer, one of whose joys in life is to plan for a better world.

As agronomists, we all recognize the importance of environment on the course of development of all living organisms. Before considering the problems of the agronomist in the post-war world directly, let us first consider briefly some of the factors in the post-war environment in which he must work. Both the physical and the social-economic-political factors of the post-war environment will be quite different from those of the pre-war world. How different in detail remains to be seen, but certain dominant aspects are clear.

On the physical side, we know that this is a war in which machines have played a more important role than ever before. "Too little and too late" has resulted in defeat after defeat for the United Nations. We have now come to realize that to win this war will require the most Herculean effort ever made by the American people. That "battle of production" is being won.

In his inspiring address before the American Chemical Society in September, Stine[3] pointed out that, "The pressures of this war are compressing into the space of months developments that might have taken us a half-century to realize if necessity had not forced the pace.

"Those pressures are unprecedented. The developments are unprecedented. Give us a victorious peace and the freedom of enterprise it should guarantee and our progress will be unprecedented. One does not need to venture into prophecy to sketch the bold lines of what that progress can be. They have already been traced. Already our world of 1940, in which we took such pardonable if mistaken pride, is so distant in the past that it has become an antiquity, as seen through scientific eyes. The inconceivables of two years ago are today's realities."

A few specific examples cited by Stine will clarify the picture. The crude rubber production of the world was raised to a million tons a year in the last century. We expect to develop a like capacity for synthetic rubber production in the United States alone in the next two years. In 1943, our production of aluminum will be almost seven times that in 1939, which was over 50 years after Hall's discovery of the electrolytic process for its manufacture. This capacity will be sufficient to build in one year three times the number of passenger cars now operating on all American railroads.

By the end of next year, we shall be producing 100 times as much magnesium as we produced before the war. In 1915, it was worth \$5.00 a pound. Today, it can be produced for 22½ cents! This makes it even cheaper per cubic foot than aluminum!

We were already referring, before the war, to the years immediately ahead as "the age of plastics." At the end of the war, the newest and most versatile of the plastics will be available on a scale beyond all previous conceptions. Our iron and steel capacity, already ample for all pre-war requirements, is being greatly expanded and will doubtless be more than sufficient to meet all post-war needs. The

[3]STINE, CHARLES M. A. Molders of a better destiny. Science, 96:305–311. 1942.

large scale development of improved alloy steels will be invaluable for many specialized needs.

Synthetic fibers of a great diversity of properties will be available in abundance. The synthetic organic chemist will be prepared to supply scores of new organics at new price lows. Motor fuels that promise to deliver 50% more power than the present 100-octane grade will be available. There has been a great increase in our capacity to produce electric power. Our machine tool industry has been vastly expanded. We have more men trained to operate them than ever before. In short, we shall have the raw materials, the power, the machines, and the trained men to perform the feats of industrial production of which men have long dreamed. This must suffice for the physical aspects of the picture.

Let us next take a glance at the prospects in the social field. President Roosevelt has said that we are fighting for four freedoms—freedom of speech, freedom of religion, freedom from fear, and freedom from want. In the United States, we have all enjoyed the first three of these freedoms as our birthright. But while there has been less want in the United States than in any large country in the world, millions of our people have known want even in the last 25 years. Freedom from want for the common man throughout the world will prove the most difficult of all the freedoms to provide. That freedom cannot be won on the battlefield nor at the peace table. Winning the war and writing the peace can set the stage. The widespread approval accorded Vice President Wallace's designation of the century ahead as "The Century of the Common Man" is, I think, an indication that the American people, at any rate, are willing to strive for freedom from want. At the Eighth Scientific Congress in Washington in 1940, Tolley[4] declared that, "A central problem of our generation is that of bringing to the people at large the great potential blessings that science has created in the last century." A similar opinion has been expressed by many other qualified scholars.

The satisfactory solution of this problem will require the sympathetic cooperation of all the people. We are learning to pull together during the war; we must continue to do so after the war. None of us should expect to have his wants handed him on a platter. Each must learn to contribute his share to the nation's and to the world's stockpile. There is an unprecedented demand for technically trained men to win the war. They will be needed just as much to win the peace. Scientists must come to grips with the intricate and, as yet, unsolved problems of distribution as well as production. The public must come to realize that, while it may be costly to keep our industrial and agricultural machinery running, it will be costlier still to let it stop! The last depression is still close enough to serve as a mild warning of what could happen.

In brief, it seems to me that the evidence at hand indicates a widespread approval of the ideals expressed in the four freedoms by the leaders and by the peoples of the United Nations. The most difficult of the freedoms to attain is freedom from want. The social,

[4]TOLLEY, H. R. Proc. 8th Amer. Sci. Congress. 5:279. 1940.

economic, and political problems involved are intricate and difficult but not hopeless. While physical resources seem ample, many important production problems await solution.

So far, I have attempted to set the stage. Let us now consider the role the American agronomist should play on this new, post-war, world stage. I say world stage advisedly, for I am convinced that the post-war services of American agronomists will not be confined within the United States.

I shall use the term "agronomist" in the same sense that it is used in our Society. I conclude from reading our constitution that an agronomist is one interested in increasing and disseminating "knowledge concerning soils and crops and the conditions affecting them".

The primary "wants" of mankind are food and clothing. Both of these are directly or indirectly products of the soil and, hence, of concern to the soil scientist. Both are also dependent, directly or indirectly, largely on field crops and, hence, of interest also to our crops specialists. In broad, general terms, we are largely responsible for the technical developments in the production of mankind's "bread and butter". I shall leave the salad and a part of the dessert to the horticulturists! Because of the very basic nature of our specialty, agronomists and agriculturists, in general, will have unprecedented opportunities to help in shaping the future of society.

Let us first consider briefly our domestic problems. The agronomist's chief responsibility in this connection is to help the farmer develop principles and practices which will enable him, first, to produce enough food, feed, and other crop products of high quality to meet all demands; second, to improve his efficiency of production so that his products can be sold at a fair price and still yield a fair profit; and third, to maintain the productive capacity of his soil. We shall need to consider each of these points in a little more detail.

We are just beginning to emerge from a period in which several important crops, wheat and cotton in particular, were produced in much larger quantities than we were able to consume or sell at profitable prices. The demands of the lend-lease program are gradually reducing the surpluses of most commodities, and rationing of other products is already under way. There seems to be little question of our ability to produce in this country adequate amounts of all of the principal crops suited to our diverse climate. There is evidence of need of some adjustment in the types of crops produced in order to bring the supplies more in line with the requirements of an adequate diet for our entire population. Considerable attention is being given to the possibilities of industrial utilization of agricultural waste products and surpluses. There will doubtless be some progress in that direction. Agriculturists should keep in mind, however, that the modern industrial chemist can destroy markets for agricultural products as well as create them. Just imagine that you owned a rubber plantation in the East Indies, and I think you will see what I mean!

Before the war, our export market for most agricultural products had sunk to an all-time low. There seems to be little evidence to indicate that it can be regained in a world at peace. I see little reason

to doubt that we can produce in this country all the agricultural products that we can consume or that we can hope to sell.

This does not mean that our job is done. It merely indicates that our major peace-time problem is not that of increasing our volume of production. Much can be done to increase the diversity and to improve the quality, particularly the nutritional quality, of our foods and feeds. Our people are more interested in adequate nutrition than ever before. The high nutritional standards in our armed forces will doubtless do much to improve the food habits of the men when they return to their homes. Better tools for assaying the nutritional value of foods have been developed and are rapidly being improved and simplified. We know but little about the effect of various environmental factors upon these different quality factors in foods and feeds. Different genetic strains of crops differ widely in the content and nature of their vitamins, fats, proteins, and carbohydrates. They offer the plant breeder an almost virgin field in which to exercise his talents. In the future, yields of dry matter and protein content will not be accepted as adequate criteria for judging the relative value of any given agronomic treatment or of a new variety or strain.

I have often been impressed by the wide range in the production cost figures obtained by farm management specialists for different farmers in the same community. Some of our New York farmers can produce 100 pounds of milk for half what it costs their neighbors. Even in the midst of the depression, a few farmers managed to make a little money. Increased efficiency of production of crops is a goal that the agronomist should keep constantly before him. I can think of no circumstances under which the farmer is liable to suffer because his production costs are too low. Economical production is sound in peace or war, in prosperity or depression. In the competition for a market, everything else being equal, the most efficient producer will win out whether the competition is between neighbors, between regions, between products, or between a domestic and a foreign producer. Artificial subsidies and barriers may bolster the inefficient producer temporarily, but it is futile to rely upon them as a permanent policy.

When I try to analyze in detail the various steps involved in crop production, there does not seem to me to be a single step that we can sort out and say, "This step is perfect. Nothing can be done to improve it". Processes which we may regard as satisfactory today may be challenged tomorrow in light of new information. I was taught that one of the important objects of plowing was to cover crop residues. Now, many agronomists are trying to find out how to plow without covering the "trash". Much of our farm machinery is in the same stage of development as the early automobiles with a dashboard and whip socket. Machines designed 50 years or more ago for operation with horses have been slightly altered to adopt them for use with the tractor. We need to make a thorough study of all the operations required in growing a crop from seedbed preparation to harvest, and after we have decided what operations are necessary for the most efficient production, we should solicit the assistance of the agricultural engineer and the farm machinery manufacturer for

designing and making the implements required. They cannot do their job until we have done ours. A few years ago, we were dissatisfied with the fertilizer distributors on the market. A complaint was made to the agricultural engineers. They asked us where we wanted the fertilizer placed with respect to the seed. We had to admit that we did not know but agreed to find out. Our Joint Committee on Fertilizer Application was set up. Cooperative experiments involving many crops, many soils, and many climatic conditions were carried out. Within a couple of years, the engineers were given their answer, and the next year, improved fertilizer distributors were available. Many farm machinery manufacturers are now using their factories for making war machines. The time would seem propitious for getting the basic information necessary for the intelligent redesigning of farm machinery. Far-sighted leaders in the field are already at work on the problem and, I am sure, would welcome the suggestions of agronomists.

The most important factor affecting crop yields in this country is still the weather. It is far more effective than any legislative control program. Many prospective agronomists are now studying meteorology in connection with the air service. They may be able to do something with the weather when the war is over. Even if they fail us, and the post-war weather remains uncontrollable, I feel that the agronomist should be able to help the farmer become more independent of the vagaries of the weather. There was a heavy hay crop in much of eastern United States this year. But the heavy rainfall, responsible in a large measure for the heavy hay crop, continued during hay harvest. As a result, much of the hay rotted in the field and much of that saved was seriously damaged by the rain. Shall we always be so helpless? Shall we always, under such circumstances, have to risk the loss of a crop which requires a whole season to grow just because we do not get an additional 8 to 15 hours of sunshine at harvest time?

Several possible solutions are being studied, grass silage, artificial drying, and barn curing; all of these seem worthy of further investigation and of more widespread farm trials.

As a direct result of the war, the capacity of our synthetic ammonia plants has been enormously increased. There seems little question but that after the war there will be available for use as fertilizer at least twice as much nitrogen as we have ever used and at a price much less than we have ever paid. A national joint committee, made up of representatives of several interested organizations, has been set up to consider the possible agricultural uses of this material. Many of you participated in this conference held in connection with this meeting. The possible industrial and agricultural implications of this development are considered by some industrial leaders large enough to have an effect on our post-war economy, "comparable to the discovery of a sixth continent".

When we consider what most of our pastures are and contrast that with what they could be, when we think of how the lespedeza rotations have affected the agriculture of Missouri and neighboring states in the last few years, when we think of what hybrid corn has done for the Corn Belt in the last decade, when we consider what a small per-

centage of the plants in the world we have tried seriously to introduce into our agriculture, I'm sure we would all agree that there is still much the agronomist can do to help the American farmer increase his efficiency of production.

I am also convinced that American agronomists have a very important international service to perform. The world seems much smaller than it did two years ago and many of its distant lands much closer to us. When the war is over, there will be millions to feed, large communities of people to be resettled, and farms to be supplied with seed, fertilizer, machinery, and livestock. A roster of qualified personnel for assisting with such work is already being prepared.

In addition to these emergency problems at the close of the war, there will be a need for American agronomists to help many countries with a primitive agriculture and, in many cases, a population larger than they can support at a satisfactory level. After long experience in public health work in such countries, the leaders of some of our large philanthropic foundations have become convinced that the best way to improve the health and general well-being of such people is to first improve their agriculture.

A high proportion of the world's farm population is still using technics that were in use in Biblical times. Contrast the human effort that goes into the production of a bushel of wheat on one of these primitive farms with that in our wheat belt. To prepare the seedbed, the soil is "tickled" three or four times with a wooden plow drawn by a pair of oxen, the seed is broadcast by hand, the wheat is harvested by cutting one handful at a time with a sickle, it is then carried or hauled to the threshing floor—often the bare ground in an open field—where it is threshed with a flail or by treading with animals! Think of doing all this work for an average yield of 8 bushels of wheat per acre! Yet wheat is being grown in this way by thousands of farmers within one day's flying time from here!

American agronomists can be of great service to the governments and educational institutions of such countries. The movement was spreading before the outbreak of the war. It will be resumed at accelerated speed after the war. Foreign students, in increasing numbers, will come to our shores for special training. Scholars from all countries should be made welcome. I hope our price level can be kept in close adjustment with that in other countries so that travel and study in America will not be beyond the reach of the ambitious young people in other countries. I would like to see our American universities far outrival the German universities of half a century ago in their influence upon science and upon the thinking of the world.

And why not? We have, or can have, the same academic freedom of which they were once so proud. We have, or can have, an equal quality of intellectual leadership. We have, or can have, physical facilities for research which will be unsurpassed in any country. I would have the scholars of the world love America. I would have them go back to their countries and instil some of that love of America in their students and other countrymen. Such friends would be America's strongest armor, her best insurance for a lasting peace. Can you conceive of any investment that would yield greater returns

to America in the way of international understanding and good will than the education of a Madame Chiang Kai-Shek?

The soil scientists of America had made a good start toward better relations with their colleagues in other countries, even before the war. Their International Congress, held in Washington in 1927, and the excursion throughout the United States which followed, gave many foreign scientists their first opportunity to study our soils and to become acquainted with us. The Second Congress in Russia in 1930 stands out in the memories of many of us as one of the outstanding treats of our professional careers. The seeds of the present conflict had been sown before our Third Congress at Oxford in 1935. An under-current of rumors and distrust was apparent to all. At the meeting of the Soil Microbiology Commission in New Brunswick, New Jersey, in August 1939, a cordial invitation to participate in the Fourth International Congress to be held in Germany in 1940 was presented. The German Organizing Committee had, even at that time, planned with characteristic thoroughness every detail of the Congress and of the excursion to follow. A few days later, war was declared, and a few weeks later, the Congress was postponed. Many of the pioneers in this Society will be missing when the war is over. New leaders must be found to take on the responsibility for its revival after the war. The job will require men of great tact and understanding.

It seems to me to be especially important for us to develop a better acquaintance and understanding with our colleagues in Latin America. A start was made at the Scientific Congress in Washington in 1940 and at the Agricultural Conference in Mexico City this summer. These conferences should be followed up with a democratic organization of the agronomists of these countries.

There is in my mind no question about the enlarged opportunities for service and the responsibilities for leadership at home and abroad that will be within the grasp of American agronomists at the end of the war. The next question is, "Do we have the men to do the job"? A decade ago, the market for young agronomists seemed to be about saturated. Able young men, well trained, equipped after years of sacrifice with a Ph.D. degree, were doing odd jobs until a real job in their field was open. A little later, the Soil Conservation Service was established. Within a short time, it had a budget greater than the soils divisions of all other state and federal organizations combined, and it was scouring the country for men with some agronomic training. The demand for well-trained men continued keenly up until the outbreak of war. Now nearly every institution or organization employing agronomists has several vacancies on its staff. Many of us are gradually becoming reconciled to the idea that many of the vacancies will have to remain unfilled until the war is won. Some of us can get a little relief by hiring men away from other institutions, but such tactics will not help the over-all shortage and should probably be confined to the normal traffic.

The graduate student enrollment in most institutions is only a small fraction of normal. It will doubtless tend to get lower as long as the war continues. At the close of the war, many of those who

were planning a career in some field of agronomy will return to our graduate schools. Many who have accepted "temporary" positions in defense industries will tend to lose touch with developments in agronomy and will probably remain in industrial work. In view of these facts, I am inclined to think that the demand for able, well-trained agronomists will exceed the supply for at least 10 years after the war is over. The only thing that I can think of which would "glut" the market would be a very drastic reduction in the support given some of our federal agencies or state institutions.

Let us consider a little further the potential post-war demand for agronomists. There are never enough "top notch" men to satisfy the demand. The demand will be keener than ever after the war. We shall need a few dreamers, far-sighted men, who can see the paths we should take and lead us and the country at large to see the potentialities for mankind that lie hidden in our soils and crops. We are, as a whole, a rather practical group, tied rather closely to the conventional approaches to our problems. For those of us who have to deal daily with farmers and their practical problems of the moment, this is highly desirable. But if we are to break new trails, we shall need a few visionary men, men broadly trained not only in the basic sciences, but in the humanities as well.

A few days ago, I heard a nationally known farm leader say that he was going to resign from several important positions so that he could have time to think about some of these problems that are going to confront agriculture after the war. In his address to chemists referred to above, Stine said, "We are going to need to be visionary to the point of audacity". If agriculture is to keep pace with industry, agriculturists must be equally bold and far-sighted.

I anticipate but a modest expansion in the number of agronomists on our college, university, and experiment station staffs. I will not even risk a guess about the future for agronomists in the United States Department of Agriculture. There is, however, another broad and practically virgin field in which the professional agronomist could render valuable service. I am convinced that a half-dozen or so extension agronomists will not be able to meet the demands for help which will arise after the war from farmers of a large state. There should be at least one professional agronomist available for consultation in every important agricultural county. In some counties, the county agent himself is qualified to handle the agronomic problems which come up in his county. More commonly, his own training is too limited and the demands on his time are too numerous to enable him to do the work satisfactorily. These county extension agronomists would not necessarily have a Ph.D. degree. They should have a good farm background, a strong undergraduate major in agronomy, topped by one or two years post graduate work in soils science, especially soil management, field crop production, farm management, and allied fields. They should be able to handle most of the individual farmers' problems. They would have the responsibility for supervising all agronomy demonstrations in their counties. Only the more difficult situations would be referred to the state extension specialist. The latter would function more largely through the county agronomy

specialists in his region and through group meetings of farmers. Plans somewhat similar to this are already in operation in sections of the country. In areas where large farming corporations are operating, such organizations could well afford to have a professional agronomist on their staffs. I understand that the sugar planters of Hawaii have established systems of agronomic management and control much more elaborate than I have outlined here, and they have found that it pays. Estates as small as 1,000 hectares in East Prussia frequently have university trained specialists in agronomy and animal husbandry on their staffs. Our agriculture consists, and will probably continue to consist, largely of relatively small, individually owned and operated farms. Some expansion of the already firmly established county agent's staff would seem the most efficient way of providing this added professional service where it is needed.

I cannot refrain at this point from commenting briefly on the organization of agronomic work in this country. The great bulk of our research and teaching in agronomy is supported by public funds. The great majority of the members of our Society are employed by county, state, or federal agencies. As public servants, there are two different points of view as to how we should conduct ourselves.

The first is that we should confine our activities strictly to our field of specialization. In other words, "stick to our last".

The other is that we, as specialists in the public service, have a certain definite responsibility for helping to develop public policy in the field of our specialization. Agronomists are still citizens and, as such, cannot escape the responsibilities of citizenship.

I feel that one of the most outstanding public services ever performed by an American soil scientist has been performed by Doctor H. H. Bennett. As a result of years of experience in studying soils, especially those of the South, he was convinced that something more had to be done to stop erosion, or the agriculture of large sections of our country would be seriously impaired. In just about a decade, he has succeeded in persuading Congress that something should be done about it, and he has made the country erosion-conscious. The nation unquestionably owes him a debt of gratitude. We need more men with his vision.

We have recently had numerous new agencies set up in the United States Department of Agriculture—many of them largely as emergency measures and presumably of temporary duration. As originally conceived, each had a rather distinct function to perform, a function which no existing organization was adequately handling. Being liberally supplied with funds, these organizations expanded rapidly. Many of them soon extended into every section of the country. Each is tending to become a Department of Agriculture within a Department of Agriculture. The result has been confusion, working at cross purposes, and friction. A very considerable proportion of the time of some of our ablest men in the agronomic field is spent in trying to iron out difficulties which should never arise. I am convinced that no intelligent man could study the existing organization of the work being done in this country in the broad field of soil science and field crop production and justify it. Agronomists in these various agencies

are earnest and sincerely anxious to do their work well. I have no solution to offer. But I am sure that none of you, especially those of you with administrative responsibilities, could ponder over "our job ahead" without having this problem of the organization of our work appear as a very vital part of the task.

A few months ago, I wrote a friend in Germany, a soil scientist who has traveled in this country and is well known to many of you, that with our traditions of democratic freedom in America, we found it difficult to understand how the intelligent German people could submit to the tyrannies of Hitler. His reply was that with our bountiful resources in America we might be able to afford liberty and democracy but that Germany is a much poorer country and must be more efficiently organized to survive! I have thought of this letter many times since the outbreak of war. Is it necessary to sacrifice efficiency in order to maintain our democratic freedom? We will all have to admit that, at times, things seem to move much more slowly in a democracy. We do more cutting and trying, more experimenting, and more compromising. We give more weight to the views of minorities. This retards action, but I think we will all agree that it increases the probability that we shall come out with the right answer in the end. Let us hope that this applies to the organization of our agronomic work. Let us hope that the present confusion represents, from the long-time point of view, merely a transitory experimental stage which will lead soon to the development of an efficient, well-integrated program. Such a development is necessary if we are to discharge fully our duties to the public. It is necessary if our services are to be more effective in helping post-war agriculture vie with post-war industry in supplying the wants of mankind.

THE PRODUCTION OF A LIME-INDUCED MANGANESE DEFICIENCY ON AN ERODED KENTUCKY SOIL[1]

G. DONALD SHERMAN, J. S. MCHARGUE, AND W. S. HODGKISS[2]

THE practice of liming strongly acid soil to a neutral or alkaline reaction has caused some soils to become manganese deficient for plant growth. Leeper (2)[3] concluded that any acid soil having less than 25 p.p.m. of easily reducible manganese dioxide becomes deficient in active manganese for plant growth if it is heavily limed. Similar results were obtained in work reported from the Michigan Experiment Station (4).

Steenbjerg (7) reported that it is more difficult to develop manganese deficiency in a clay soil than in one of a sandy character. He explained this by suggesting that the clay colloid held the manganese.

It is necessary to define some of the terms given above in order that the reader may clearly understand them. Leeper (2) believes that the manganese of the soil exists in an oxidation-reduction equilibrium. This equilibrium exists between the exchangeable manganese (manganous) and a continuous series of manganese of a higher state of oxidation (manganic), including a range from the most active to that which is relatively inert. For the sake of convenience only, he has called this series of manganese, manganese dioxide, realizing that they include compounds in which the manganese exists in varying degrees of oxidation above the manganous form. The active portion of this group, easily reducible manganese dioxide, is extracted by a solution of neutral normal ammonium acetate containing 0.2% hydroquinone after the water-soluble and exchangeable manganese have been removed from the soil. Active manganese is the total amount of manganese found in the leachates from the successive extractions of the soil with distilled water, a solution of neutral normal ammonium acetate, and a solution of neutral normal ammonium acetate containing 0.2% hydroquinone (5). In general, the water-soluble manganese in most soils was found to be less than 0.2 p.p.m. and for that reason was not determined in this study.

In general, the soils of Kentucky are abundantly supplied with manganese (3). The distribution of the manganese in the soil profile is similar to that reported in the work of Alexander, Byers and Edgington (1). The results of their work showed a high content of manganese in the soil and the colloidal fraction of the A horizon. There was an indication that the surface was enriched by manganese moving upward in the soil profile, as there was a depletion of manganese in the B horizon. The distribution of exchangeable manganese and of easily reducible manganese dioxide in the horizons of some typical

[1]Contribution from the Department of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication June 27, 1942.

[2]Formerly Assistant Chemist, now Assistant Chemist, Southern Regional Laboratory, New Orleans, La.; Head of Department; and Assistant Chemist, now with General Printing Ink Co., New York City, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 1083.

TABLE 1.—*The profile distribution of exchangeable manganese and of easily reducible manganese dioxide in some typical Kentucky soils.*

Horizon	Depth, in.	Exchangeable manganese, p.p.m.*	Easily reducible MnO_2 ($Mn++$), p.p.m.*
Maury Silt Loam, Scott County			
A1	0–8	3.0	541
A_2	8–20	3.2	669
B_1	20–40	6.7	315
B_2	40–64	2.7	339
C	64–82	2.3	921
Shelbyville Silt Loam, Franklin County			
A	0–7	3.3	331
B	7–18	3.2	86
C	18–32	3.2	562
Cincinnati Silt Loam, Henry County			
A	0–6	3.6	627
B	6–16	3.9	291
C	16–32	3.1	372
A Sandstone Soil, Knobs Region (Unclassified), Jackson County			
A	0–6	4.0	339
B	6–14	2.3	31
C	14–33	1.2	1
A Limestone Soil, Adair County (Unclassified), Decatur Type			
A	0–8	2.6	501
B	8–22	2.3	127
C	22–40	1.0	2

*Determination by method described by Sherman, McHargue, and Hodgkiss (5).

Kentucky soils is shown in Table 1. In the Maury silt loam, a soil having a very high "active" manganese content in all horizons of the profile, the B horizon was lower than either the A or C horizon, in easily reducible manganese dioxide. The Shelbyville silt loam and the Cincinnati silt loam showed a similar profile relationship. The relatively uniform distribution of the active manganese dioxide may be attributed to the high level of available phosphorus and calcium in these soils. In them the manganous-manganic equilibrium is well stabilized toward the formation of the manganic oxides. This can be demonstrated very clearly in the following manner. A known quantity of manganous sulfate is mixed into any one of the soils of this group. The soil is placed in a tumbler and enough water added to have optimum moisture conditions. After 12 hours the soil is removed and the determination of water-soluble and exchangeable manganese and the easily reducible manganese dioxide are made. The data obtained will show that 50% of the added manganese will be in the form of easily reducible manganese dioxide. Only about 2% of the added manganese will be recoverable in the manganous forms. The remainder has been converted to forms insoluble in the extraction reagents used. The relationship between qualities of manganous and

manganic manganese does not change much during the year and can be considered a stable system. This is further indicated by the presence of ferruginous pellets containing manganic oxides throughout the soil profile. The high content of active manganese in these soils will not produce toxic effects to plant growth because of the stability of the oxidation-reduction system in keeping the manganese in the manganic form.

The soil profiles from the Knobs Region and from Adair County are outside the Bluegrass Region. These soils are strongly acid and low in both available calcium and phosphorus. The profile distribution of the active manganese of these soils showed a very definite enrichment of the A horizon, presumably at the expense of the other horizons of the profile. These soils have a very unstable manganous-manganic system which has permitted the movement of the soil manganese to the surface horizon. The addition of manganous sulfate to these soils in the same manner as was described for the soils of the Bluegrass Region will show a different manganous-manganic relationship when the active manganese is determined. Ninety per cent of the added manganese can be recovered in the active forms. Fifty per cent of the added manganese will be in the manganous forms and 40% as easily reducible manganese dioxide. This manganous-manganic relationship will change quickly with changes in soil conditions. If lime is added to these soils, the manganous manganese will decrease to a few p.p.m. and the easily reducible manganese dioxide will increase many times. The addition of phosphate will do the same thing. These soils in their natural condition have a very unstable manganous-manganic system. If this profile were subjected to excessive leaching, the manganese would be removed but, since it is not, the manganese is brought to the surface probably by capillary action and is thus concentrated. The C horizon of these soils contained a very small amount of easily reducible manganese dioxide.

The field adjacent to the location of the profile from Adair County is badly eroded. Both the A and B horizons are almost completely removed. Since this subsoil is extremely low in active manganese it was considered possible to produce a manganese deficiency by liming it to an alkaline reaction. The subsoil has a very high content of clay and for this reason it would be interesting to determine the influence of clay on the availability of the soil manganese.

COMPARISON OF EFFECT OF LIMING A HIGH-MN SOIL AND A LOW-MN SOIL

Two clay subsoils were found, one having a high and the other a low active-manganese content. The badly eroded subsoil from Adair County was taken as a soil having an extremely low active-manganese content. This soil has a pH of 5.2 and a total manganese content of 71 p.p.m. A similar subsoil was found in Larue County which had a higher active manganese content, 28 p.p.m., and a total manganese content of 144 p.p.m. The pH of this soil was 5.1. The texture of the two soils was about identical, both being clay soils. The Larue County soil was more granular in structure than was the Adair County soil.

Twenty half-gallon glazed jars were filled with soil from each of these two locations. Each jar received chemically pure salts equivalent to an application of 1,000 pounds per acre of a basal fertilizer of the ratio 4–7–14. In addition to the basal fertilizer four jars of each soil received $CaCO_3$; $CaCO_3$ and $MnSO_4$; $CaCO_3$ and $CuSO_4$; and $CaCO_3$, $MnSO_4$, and $CuSO_4$. Four control jars received only the basal fertilizer. Calcium carbonate was applied at the rate equivalent to 4 tons per acre. All fertilizer, lime, and Mn and Cu salts were mixed into the soil in their solid forms.

The jars were seeded to Wolverine oats on January 26, 1942. Wolverine oats have been found to be very susceptible to the development of grey speck (4). The oats grown on the Adair County soil which received the lime developed the characteristic lesions of grey speck. The growth of the oats on it was poorer than that of the oats on the soil which did not receive lime. The oats grown on the soils receiving copper or manganese in addition to lime were considerably better than those on the soil which did not receive lime. Application of lime to the Larue County soil improved the growth of the oats. The oats were harvested on April 4, 1942, and the findings are given in Table 2. The yield of oats on both soils which did not receive lime was almost the same, being 64.5 grams for the low-manganese soil and 65.2 grams for the high-manganese soil. The addition of lime to the low-manganese soil depressed the yield of oats to 34.4 grams, while the same treatment on the high-manganese soil increased the yield approximately 40 grams. Application of manganese sulfate or copper sulfate increased the yield of oats over that produced on the control, which is very significant. The same treatments to the high-manganese soil did not influence the yields perceptibly. Fig. 1 shows oats growing on the low-manganese soil receiving each of the four

TABLE 2.—*Effect of liming an acid clay soil low in active manganese and a similar soil high in active manganese on the yield and composition of the oats grown thereon, average from four jars in each group.*

Treatment equivalent in pounds per acre*	Adair County, low manganese			Larue County, high manganese		
	Average yield, grams	Manganese content, %	Copper content, %	Average yield, grams	Manganese content, %	Copper content, %
Control	64.7	0.0258	0.00012	65.2	0.0201	0.00013
8,000 lbs. $CaCO_3$	34.4	0.0029	0.00006	112.4	0.0046	0.00010
8,000 lbs. $CaCO_3$+ 100 lbs. $MnSO_4$	101.5	0.0528	0.00013	115.4	0.0476	0.00013
8,000 lbs. $CaCO_3$+50 lbs. $CuSO_4$	97.8	0.0058	0.00031	106.1	0.0128	0.00029
8,000 lbs. $CaCO_3$+100 lbs. $MnSO_4$+50 lbs. $CuSO_4$	93.1	0.0518	0.00023	125.1	0.0514	0.00020

*All jars received an NPK fertilizer at a rate equivalent to 1,000 pounds per acre of a 4–7–14 fertilizer.

treatments in addition to the basal fertilizer which was applied to the soil in all jars.

The manganese and copper content of the oat plants are given in Table 2. Manganese was determined by the usual periodate method, and copper by an adaptation of the method described by Sherman and McHargue (6) for the determination of copper in soil. The application of lime to the soil depressed the manganese content of the oats. The oats grown on the low-manganese soil which received lime contained 0.0029% manganese and that grown on the unlimed soil 0.0258%. The oats from the same treatments on the high-manganese soil showed 0.0046 and 0.0201% manganese, respectively. The oats grown on the soil which received copper in addition to the lime did not show as low a manganese content as did that grown on the limed soil. The manganese content of the oats grown on the low-manganese soil receiving copper and lime was higher than that in the oats grown on the high-manganese soil receiving lime alone. The application of manganese sulfate gave a marked increase in the manganese content of the oats wherever it was applied.

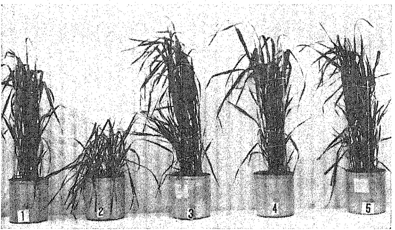


FIG. 1.—Wolverine oats on Adair County soil low in active manganese, with a 4-7-14 fertilizer at a rate equivalent to 1,000 lbs. per acre and the following additions stated as equivalent pounds per acre: Jar 1, control; jar 2, 8,000 lbs. $CaCO_3$; jar 3, 8,000 lbs. $CaCO_3$+100 lbs. $MnSO_4$; jar 4, 8,000 lbs. $CaCO_3$+50 lbs. $CuSO_4$; jar 5, 8,000 lbs. $CaCO_3$+100 lbs. $MnSO_4$+50 lbs. $CuSO_4$.

The exchangeable manganese and copper and the easily reducible manganese dioxide were determined in soil receiving each of these treatments by a method similar to the one proposed by Sherman, McHargue, and Hodgkiss (4). The findings are given in Table 3. The exchangeable copper was increased in both soils when copper sulfate was applied. The application of lime did not have a marked influence on the exchangeable copper in either soil.

The exchangeable manganese in both soils was decreased by the application of lime. The low-manganese soil has 0.1 p.p.m. of ex-

changeable manganese after liming as compared with 0.6 p.p.m. for the same treatment in the high-manganese soil. The depression of exchangeable manganese was less on the soil receiving copper with lime. Application of manganese sulfate resulted in a considerable increase in the exchangeable manganese. When copper and manganese sulfates were applied with lime, the exchangeable manganese in the soil was twice that in the soil receiving manganese sulfate and lime. The copper apparently retarded the oxidation of the manganese to the higher oxides. Other investigations with other soils have given results which support this contention.

TABLE 3.—*Effect of application of lime alone and in combination with copper and manganese to soils low and high in active manganese on the yield of oats and on the active manganese and copper in the soil.*

Treatment in pounds per acre*	Adair County, low manganese				Larue County, high manganese			
	Exchangeable Cu, p.p.m.	Exchangeable Mn^{++}, p.p.m.	Reducible MnO_2 Mn^{++}, p.p.m.	Average yield, grams	Exchangeable Cu, p.p.m.	Exchangeable Mn^{++}, p.p.m.	Reducible MnO_2 Mn^{++}, p.p.m.	Average yield, grams
No treatment	0.08	1.0	2.1	64.7	0.08	2.8	3.9	65.2
8,000 lbs. $CaCO_3$	0.06	0.1	0.0	34.4	0.11	0.6	1.0	112.4
8,000 lbs. $CaCO_3$ + 100 lbs. $MnSO_4$	0.08	2.7	15.6	101.5	0.09	4.9	22.3	115.4
8,000 lbs. $CaCO_3$ + 50 lbs. $CuSO_4$	0.35	0.4	1.4	97.8	0.32	1.0	1.9	106.1
8,000 lbs. $CaCO_3$ + 100 lbs. $MnSO_4$ + 50 lbs. $CuSO_4$	0.28	4.4	15.6	93.1	0.29	7.6	23.8	125.1

*All jars received an application equivalent to 1,000 pounds per acre of 4-7-14 fertilizer.

Easily reducible manganese dioxide is markedly lower in the soil which received lime as compared with that in the control. The application of copper sulfate with lime did not depress this form of manganese as did lime alone. Application of manganese sulfate produced 15.6 p.p.m. of easily reducible manganese dioxide in the low-manganese soil as compared with 23.0 p.p.m. for the high-manganese soil. Both these values are low according to the critical values established by Leeper (3).

DISCUSSION

Two very similar acid subsoils, exposed by erosion, were overlimed in a pot experiment in an effort to induce deficiency of manganese and possibly of copper for the normal development of plants. These soils were derived from similar parent material, limestone, and were almost identical in physical characteristics. Chemically, they differed in content of active manganese. The active manganese content of both was low as compared with other soils known to be manganese deficient. When these soils were limed to an alkaline reaction, the

one having the lowest active manganese content, the Adair County soil, became manganese deficient in respect to the growth of oats. The well-known manganese-deficiency symptom of oats, grey speck, was produced on the oats grown on the soil receiving lime. Addition of manganese sulfate with the lime prevented the development of grey speck. Application of lime caused fixation of the manganese in a form very unavailable to the plant. Apparently, added copper retarded the oxidation of manganese to the higher oxides, thus permitting the plant access to a limited but sufficient supply of manganese. This effect of copper has not been suggested in previous research in the minor-element field.

The influence of the clay fraction of these soils on the manganous-manganic equilibrium is quite interesting. Since the soil clay minerals are acidic, their influence upon the manganous-manganic equilibrium should be similar to that of applied sulfur (3). Application of lime caused the manganous manganese to be oxidized. The clay fraction, acting as an acid, tended to reduce the manganic manganese and to retard the oxidation of the manganous ion. The application of lime apparently did not overcome the counter effect of the clay. The active manganese content of these soils, therefore, must be extremely low before overliming injury can be produced. The critical content of active manganese in a clay soil is much lower than that for a sandy soil.

Steenbjerg (7) has proposed a theory somewhat different from the one proposed here. He explained this phenomenon on the basis of the retentiveness with which the clay colloid held the manganous ion. According to his contention, it would be more difficult for this manganese to be oxidized under these conditions. The plant roots could obtain this manganese by the ordinary exchange reaction.

The distribution of manganese in the profile of the Kentucky soils tested was found to be similar to that in most gray-brown podzolic soils. These soils have shown a characteristic high content of manganese in the A horizon. The manganese content of the B horizon of these soils has been found to be lower than that of either the A or C horizon (2). The manganese content of the colloidal fraction of the A horizon was much higher than that of the other horizons. The subsoils of many of these soils are extremely low in active manganese. Severe erosion in these soil areas will bring to the surface a soil which will be deficient in active manganese for plant growth. Liming these soils in badly eroded areas to a neutral or alkaline reaction should be avoided. The soil from Adair County can be taken as an example as to what might happen if such a condition were produced.

SUMMARY

1. Manganese deficiency can be induced by liming an acid clay soil to a neutral or alkaline reaction provided the active manganese is extremely low in the original soil.
2. The amount of active manganese in an acid clay soil must be considerably lower than that of a sandy soil in order to produce overliming injury.

3. The soil clay minerals retard the oxidation of manganous manganese in a manner similar to that of a true acid.
4. The application of copper sulfate with the lime retarded the oxidation of the manganous ion sufficiently to provide a limited but adequate supply of active manganese for the normal growth of oats.
5. Application of calcium carbonate to an acid soil having a supply of active manganese too high for plant growth depressed the amount of manganous manganese in the soil, thus causing increased plant growth.
6. The difference between the level of active manganese in a strongly acid clay soil which will show manganese-deficiency and one which will show manganese toxicity is apparently quite small.
7. Many of the soils belonging to the gray-brown podzolic group have most of their active manganese concentrated in the A horizon. Erosion of these may expose a subsoil which may be deficient in manganese.

LITERATURE CITED

1. ALEXANDER, L. L., BYERS, H. G., and EDGINGTON, G. A. Chemical study of some soils derived from limestone. U. S. D. A. Tech. Bul. 678. 1939.
2. LEEPER, G. W. Manganese deficiency of cereals, plot experiments and a new hypothesis. Proc. Roy. Soc., Victoria, 47, II; 255–261. 1935.
3. SHEDD, O. M. The occurrence of manganese in Kentucky soil and its possible significance. Jour. Ind. & Eng. Chem., 6:660. 1914.
4. SHERMAN, G. DONALD, and HARMER, PAUL M. Manganese deficiency of oats on alkaline organic soils. Jour. Amer. Soc. Agron., 33:1080–1092. 1941.
5. ————, MCHARGUE, J. S., and HODGKISS, W. S. Measurement of the active manganous-manganic manganese equilibrium in soils. Soil Sci., 54: 253–257. 1942.
6. ———— and MCHARGUE, J. S. Methods for determination of copper and zinc in soil. Jour. A. O. A. C., 25:510–515. 1942.
7. STEENBJERG, F. The exchangeable manganese in Danish soils and its relation to plant growth. Trans. 3rd Int. Congress Soil Sci., Oxford, 198–201. 1935.

RESULTS FROM INBREEDING UPLAND COTTON FOR A TEN-YEAR PERIOD[1]

H. B. Brown[2]

SINCE inbreeding, followed by the selection of pure lines, is probably the surest and quickest way of making a strain of cotton uniform, considerable interest is attached to the question as to whether or not inbreeding has a tendency to reduce the vigor and productivity of the plants. In some cases where close selection has been practiced for a number of years and relatively pure strains produced, the acre yields have apparently become lower. However, other factors may have been partly responsible.

It is the general consensus of opinion among geneticists that close breeding in the human race and among the higher animals may be harmful if the constitution of the parents is in some way defective; otherwise, no harm results. Close breeding is the nearest approach to inbreeding that can be made among these groups. Probably the same principles also hold true for plants. But here, conditions may be more extreme in that there is true inbreeding, resulting from self-pollination.

A review of the literature of the past 30 years shows that considerable study has been devoted to the effect of inbreeding on plants. It has been found that inbreeding tends to reduce vigor and productiveness in the majority of species. However, there are some that apparently are not affected adversely. Some very uniform, pure, productive strains have been produced in this way.

Among the plants reported as being injured by inbreeding are corn, rye, potatoes, radish, rape, bluestem grass, and species belonging to the genera *Brassica*, *Primula*, *Hyacinthus*, *Crepis*, *Fresnia*, and *Pennisetum*. Squash, watermelons, and cabbage were affected but slightly, while sorghum, some varieties of cotton, and certain other plants have been reported as not being changed at all.

Most of the cotton inbreeding work has been done on species or varieties other than upland. Leake and Prasad (5)[3] of India report that certain cottons of the Asiatic type retained fewer bolls comparatively when inbred one or more generations, but that later crossings tended to overcome this effect.

Pressley (6) in Arizona found that hybrid seed were slightly larger and that hybrid lint was slightly longer than regular seed and lint.

Brown (1) noted that a first generation hybrid between selfed strains of Cleveland and Express, two upland varieties, produced plants 4 inches taller than either parent strain and bore 25% more bolls.

Kearney (3) in extensive inbreeding experiments with Pima Egyptian cotton in Arizona observed that inbreeding during seven generations brought about no reduction in the daily rate of flowering, in the percentage of bolls retained, in the size, weight, and seed content of the bolls, in the weight and viability of the seeds,

[1]Contribution from the Louisiana Agricultural Experiment Station, Baton Rouge, La. Received for publication July 2, 1942.

[2]Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 1089.

nor in the abundance of the fiber as compared with those of the continuously open-pollinated stock.

Humphrey (2) of Arkansas inbred eight different upland varieties for a period of years. He found that inbreeding tended to produce strains with more uniform staple length and plants with more uniform lint percentage, but there was but slight improvement along these lines after the third year. No comparison is made by Humphrey between the lint length and the lint percentage of the inbred strains and their open-pollinated parents. The figures given in his tables, however, show a shorter staple length and lower lint percentage as the inbreeding progressed.

Inbred strains of eight upland varieties grown in comparison with their open-pollinated parents by Winston Neely of Stoneville, Mississippi, were observed by the writer during the season of 1941. In every instance, the height of the open-pollinated plants was greater than that of the selfed strains, the average in their favor being 6 inches. Two of the selfed strains averaged 10 inches lower than the open-pollinated strains of the same variety.

LOUISIANA EXPERIMENTS

In 1928, an experiment was started at the Louisiana Agricultural Experiment Station to measure the effect of inbreeding upland cotton for a period of years. Fifty typical plants were selected in each of eight commercial varieties, an effort being made to cover the range of varietal types grown in Louisiana at that time. Two bolls were self-pollinated on each of the 50 selected plants of the variety, and likewise two bolls on each of the same 50 plants were cross-pollinated with pollen from other plants of the selections. Seed from these 100 selfed bolls were massed to avoid any effect of selection, and seed of the crossed bolls were likewise massed. Alternate rows were planted from each in 1929. Bolls were selfed on plants in the rows from selfed seed, and likewise bolls crossed on plants of the crossbred strains. The rows were widely spaced to avoid border effect and to get good yields from the plants grown. It was not convenient to have large numbers of plants each year due to the fact that all the seed used had to come from hand-pollinated flowers. There were, however, from 1,000 to 2,000 plants grown each year; the number in the rows of the pairs that were being compared was always the same.

This process was continued each year for a 10-year period. Various characters of the plants in the pairs of rows that were being compared were studied each year, including height of seedling plants, height of plants at maturity, blooming rate, boll size, cotton production, lint percentage, staple length, etc. Experimental errors due to differences in soil fertility, in different parts of the plots, differences in plant diseases, insect damage, and other unavoidable influences affected the results during certain years and produced some inconsistencies. These largely disappear, however, when the averages for a period of years are considered.

As was stated previously, an effort was made in the Louisiana experiments to include the main varietal types being grown in the state at the time the experiment was started. The following varieties were used: Trice, Wannamaker Cleveland, Dixie Triumph, Triumph 406, Acala, D. & P.L. 6, Delfos 6102, and Deltatype Webber. Seed was obtained from the originator of the variety in most cases and represented a relatively pure commercial strain in all cases, but they were not genetically pure. Some of the strains used, like Wannamaker Cleveland, for instance, had been line-selected for 20 years or more, while other strains, like D. & P.L. 6, were hybrids from recent crosses. From the studies made, it was not possible to see that the previous handling of a strain made much, if any, consistent difference in the effect of the inbreeding.

EFFECT OF INBREEDING ON VARIOUS CHARACTERS OF THE COTTON PLANT

In this study an attempt was made to get a measure of the effect of inbreeding on several of the more important characters of the cotton plant.

Seed germination.—Field germination counts of inbred and cross-pollinated strains were made each year for a period of 7 years. The percentage of germination varied somewhat in different years due to the effect of weather on the quality of the seed planted, but the inbreeding seemed to have no consistent effect.

Vegetative growth.—Both height and width of plant measurements were made, the height measurements being taken for 10 years and the width or spread of plants for 5. The actual, as well as the relative, height of plants varied with the time of measurement. During the latter part of the season, plants tended to become large where there was plenty of moisture and the soil was fertile. Plants with fewer bolls became larger than ones that were well fruited. On the average for the 10-year period, the plants of the crossed strains were slightly taller than the selfed strains, but the difference was not significant. Each year the lateral spread of the crossed plants was slightly greater than that of the selfed, the average difference ranging from a fraction of an inch to 2.6 inches.

In 1934, after cotton picking, all the plants of two series were pulled up and weighed individually. The average plant weight of the crossed plants was 12.58 pounds and of the selfed 11.93 pounds.

Number of blooms.—During each year for the entire 10-year period, bloom counts were made to get a measure of the relative blooming rate of the strains that were being compared. Counts were made every two or three days during the blooming period. This was enough to get a representative sample of the rate of blooming. In 8 years of the 10, the crossed strains averaged more blooms than the selfed, Delfos 6102 being the only variety in which the selfed strain led. For the 10-year period, the crossed strains did 6.2% more blooming than the selfed. As the experiment progressed, the trend was toward a wider spread between rates. In 1929, the selfed strains did 0.3% more blooming than the crossed strains. In 1938, the crossed strains did 7.8% more than the selfed strains.

Boll size.—Boll weights for all the varieties were taken each year for a 7-year period. The bolls of the two strains of two of the varieties used were very nearly the same size, but for the other six varieties the difference was greater with the crossed strains being the larger. Taking the average of all varieties, the crossed bolls were consistently heavier every year (Fig. 1). The crossed bolls averaged 9.3% heavier than the selfed bolls.

Earliness as shown by boll opening.—In 1937, open bolls were counted on one set of plots on August 16. This was soon after boll opening began and consequently not many were open, but it did give some measure of the relative earliness of the strains (Fig. 2). Seven of the eight varieties used showed more open bolls on the crossed strains, the average lead of all crossed strains being 28.7%.

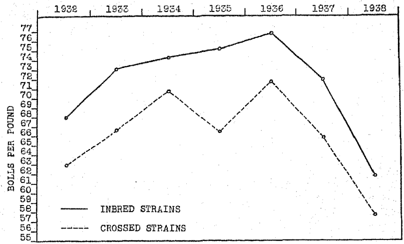


FIG. 1.—Number of bolls per pound.

Staple length.—The staple length of all varieties was measured each year during the experiment. In most cases, the difference in length was not more than 1/32 inch. In some cases, the crossed strains were longer, in others the selfed strains. Since the difference in length was slight and as there seemed to be no consistency in the difference, it is doubtful if it was of any significance.

Lint percentage.—Samples of seed cotton from all the strains were ginned each year to obtain lint percentage. In 9 cases out of 10, the crossed strains had the higher annual average. The 10-year average for the crossed strains was 32.5% and for the selfed strains 32.2%, a difference that was consistent but probably not great enough to be significant.

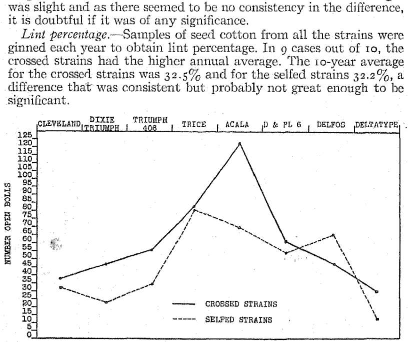


FIG. 2.—Number of open bolls on August 16, 1937.

Weight of seed cotton.—In 1929 and again in 1938, every crossed strain produced more seed cotton than the corresponding selfed strain. During 9 years of the 10, the crossed strains led in production, the margin in their favor being greater by 9.3% (Fig. 3). This difference was fairly consistent and significant, the odds being 550 to 1 when comparison was made by Student's method for paired comparison.

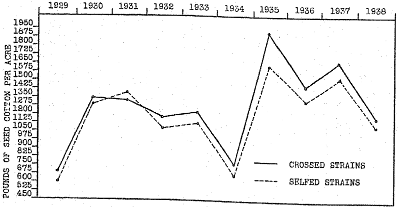


FIG. 3.—Comparative yields of crossed and inbred strains.

DISCUSSION

A number of irregularities and inconsistencies appeared in results at different times during the course of the experiment. These were largely due to adverse experimental conditions, such as slight differences in soil fertility, soil moisture, insect damage, and fungous diseases in different parts of the plots used. Although there were some inconsistencies in individual cases, the averages for the several varieties for the whole number of years indicated rather definite trends. The crossed strains had greater vegetative growth, did more blooming, had larger bolls, opened bolls earlier, and had greater production of seed cotton, indicating greater vigor and fruitfulness. The difference between strains was not great, but it was great enough and regular enough to mean something. Although the inbreeding used in this experiment had some detrimental effect on the selfed plants, its effect was not great enough to prohibit cotton breeders from using it as a method of securing uniformity of their strains. Open-pollinated cotton flowers have a high percentage of their ovules self-fertilized normally, so the difference in production between the inbred and the open-pollinated strains would probably not be so great as the difference obtained in this experiment.

New varieties of cotton usually yield best when first introduced. In cases observed by the writer, there has usually been a rather steady reduction in production as the strain became older, even if it was kept pure. Numerous selections made within the strain have usually not been effective in maintaining its production. Some varieties that

have been line-selected for a number of years have gained in uniformity but have fallen in production.

Humphrey (2) reported that his inbred strains rapidly became more uniform. He must have selected out and propagated from relatively pure lines. In our inbreeding work in which seed was saved from all the plants and massed, the strain tended to become less uniform. That is easily explained because all segregations and forms that appeared were preserved. Our crossed strains became more uniform than the selfed because here there was a continued blending of characters from different plants.

Kearney (3), working with Pima Egyptian cotton for a 7-year period, failed to get any reduction in growth and production from inbreeding. A possible explanation of this may be found in the fact that plant selections were made each year and propagation was from these select productive plants. Probably selection in this case had much the same effect that it did with white rats in the experiment carried on by King (4). In that instance, inbreeding, coupled with rigid selection for 40 generations, resulted in no deterioration, but in equal, and in some ways, superior stock.

SUMMARY

1. In general, inbreeding plants and animals results in loss of vigor.
2. In some cases, inbreeding, accompanied by selection, has had no harmful effect.
3. In most instances reported, inbreeding cotton has caused some deterioration.
4. Inbreeding eight varieties of Upland cotton at Baton Rouge, La., for a period of 10 years resulted in an average reduction of 9.3% in production of seed cotton, a 6.2% reduction in blooming rate, and a 9.3% reduction in boll size.

LITERATURE CITED

1. Brown, H. B. Cotton. New York: McGraw-Hill Book Co.
2. Humphrey, L. M. Effects of inbreeding cotton with special reference to staple length and lint percentage. Ark. Agr. Exp. Sta. Bul. 387. 1940.
3. Kearney, T. H. Self-fertilization and cross-fertilization in Pima cotton. U. S. D. A. Bul. 1134. 1923.
4. King, Helen D. Is inbreeding injurious? Rpt. 2nd Int. Congress of Eugenics, 1:270–277. 1923.
5. Leake, H. M., and Prasad, R. Notes on the incidence and sterility and of cross-fertilization in the Indian cottons. Mem. Dept. Agr. India, Bot., 4:37–72. 1912.
6. Pressley, E. H. A study of the effect of pollen upon the length of cotton fibers. Ariz. Agr. Exp. Sta. Tech. Bul. 70. 1937.

A STUDY OF THE EFFECTS OF SILTY IRRIGATION WATER FROM AN INTERMITTENT STREAM ON CROPS AND SOILS IN CONTROLLED PLOTS[1]

J. L. GARDNER AND D. S. HUBBELL[2]

THE loss of water as surficial runoff is particularly serious in such regions of scant rainfall as the southwestern United States, where as much as 25 to 50% of the rainfall of a single storm may be lost as flash floods in intermittent streams. These flows carry with them large amounts of sediment and organic debris, thus depleting the soil of the upper reaches of the watershed, channeling with deep arroyos the broader valleys, and emptying large quantities of mud into the living streams, many of which feed expensive irrigation reservoirs. Probably the ideal solution from the standpoint of soil and water conservation would be to check this water at or very near its source. In many cases, however, this is highly impracticable.

The use of flash flood waters from intermittent streams for the growing of crops has, according to Stewart (8)[3] and many others, been practiced for centuries by both the historic and the prehistoric Indians of the Southwest and by the whites as well (2). The water was either diverted by dikes or used where it spread out naturally over a fan. Although such irrigation is still used by the Pueblo and the Navajo Indians and by the whites, the acreage thus subjugated has decreased (2) since 1880, owing to the cutting of deep arroyos. Elsewhere, too, runoff water is being used similarly, e.g., in the state of Washington (5) and on native vegetation in Montana (1, 6) and Colorado.

Usually there has been little or no control of the water. Farming under such conditions is precarious, since the crops may be washed out or buried in sediment. If, however, reasonably safe methods could be devised for utilizing some or all of the water from intermittent arroyo flows, it should be possible to conserve it for plant production and at the same time to check the large amounts of sediment which otherwise finds its way into the reservoirs on the living streams below.

In spite of the antiquity of the practice of flood water farming, no exhaustive studies have been made of the vegetational or edaphic reactions. Experiments were started at the Navajo Experiment Station in 1935 to investigate the effects of flooding on native vegetation and soils, and in 1938 these were extended to include similar studies on crops in controlled plots. The present paper is a report on results from the crop plots after 3 years of treatment.

The sediment-laden water used in these studies was diverted from Mexican Springs Wash, an intermittent stream which flows when there is runoff from melting snow or heavy rainfall in the hills above. During the period of study most of the runoff has occurred just

[1]Contribution from the Soil Conservation Service, Navajo Experiment Station, Mexican Springs, N. M. Received for publication July 6, 1942.
[2]Associate Soil Conservationist and Project Supervisor, respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 1101.

previous to or during the growing season. The early spring flows have contained only about 1% of sediment by weight. The later flows have carried as much as 29% of sediment by weight.

PLAN OF EXPERIMENT AND ARRANGEMENT AND TREATMENT OF PLOTS

Sixty plots, 18 feet by 25 feet inside measurement, are being used in the study. These plots are separated from each other by earthen dikes. The flume which carries water to the plots lies on a dike which is 6 feet wide at the base. A diagram of the plots is shown in Fig. 1. The crops grown are a yellow flour-corn used by the Navajo Indians, pinto beans, and oats.

The plots are spaded to a depth of about 7 inches in late November. Besides facilitating the absorption and retention of winter moisture, fall spading seems to reduce the number of cut worms the following spring. This is a very real consideration, since, if not controlled, these pests may reduce a perfect stand of corn by half or more in the course of a week. Planting is done as near May 20 as practicable; harvesting, in October.

The treatments are replicated four times in randomized blocks. Twenty-four plots lie along either side of the flume, which is equipped with automatic gates and measuring devices to deliver water in known amounts (Fig. 2). The other 12 receive no water except precipitation. Of the 48 irrigated plots, 24 are treated with silty water, half of them receiving a 6-inch application each time the wash flows and half receiving 6 inches from flows which are selected for timeliness and low sediment content. Of the remaining 24 plots, half receive 6 inches of clear well-water each time silty water is applied to the "all-flow, silty-water" plots; and the other 12 are watered with 6 inches of clear water each time the "selected-flow, silty-water" plots are watered. At times when the "all-flow, silty-water" plots have been too full to hold another 6 inches of water, applications of 3 inches have been added and the corresponding "clear-water" plots have been given 3 inches of clear water. A summary of treatments is given in Table 1.

TABLE 1.—*Summary of plot treatments.*

Crop	All flows		Selected flows		Precipitation only
	Silty	Clear	Silty	Clear	
Corn	4*	4	4	4	4
Beans	4	4	4	4	4
Oats	4	4	4	4	4
Total	12	12	12	12	12

*Number of plots.

FLUME AND MEASURING DEVICE

To meet the requirements of measuring and sampling the applied water, the mechanism shown in Fig. 2 was designed.[4] By means of this device, a continuously taken aliquot sample of the flow is obtained; and, at the same time, the water flowing onto the plot is measured. Tests have shown that, using water without

[4]Mr. George Antonick, general mechanic, designed and constructed this device.

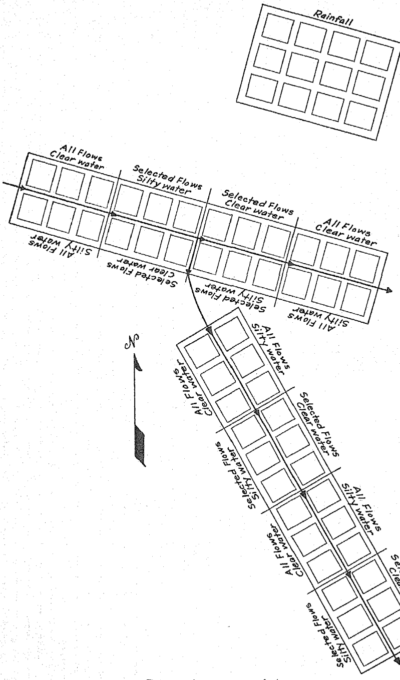


FIG. 1.—Arrangement of plots.

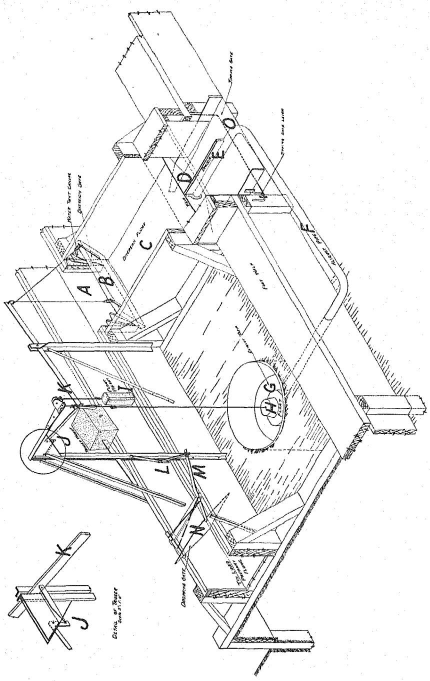


FIG. 2.—Diagram of automatic flume gate.

trash, the maximum errors of measurement are about 5%. When the flow carries trash, the divisor must be kept clean if an accurate aliquot is to be obtained.

Using the diagram in Fig. 2 as a guide, a description of the functioning of the device follows:

The plot gate, B, is opened by hand, and the trigger mechanism at J is set. Water from the main flume, A, flows into the plot flume, C; flows over the weir, D; drops into the tipping flume, O; and flows onto the plot. The aliquot portion is is taken out by the divisor, E, and is led through the pipe, F, into the reservoir, G. The float, H, is so set that, when the desired amount of water has flowed over the weir to the plot, the water in the aliquot reservoir raises the float. As the float is raised the trigger at J is tripped, and the weighted lever, K, is released. As K falls it closes the gate, B, and, at the same time, trips the series of levers at L and M. This opens the flap-gate, N, and the water flows on down the main flume.

After an irrigation the water in the aliquot reservoirs is thoroughly stirred with a broom and sampled with a pipe sampler. These samples are analysed in the laboratory for percentage of sediment by weight, mechanical characteristics of the sediment, and total quantity of dissolved salts.

RESULTS AND DISCUSSION

Table 2 shows the amounts of water and of sediment which the plots received during 3 years of treatment. The depth of deposit at the end of this period averaged between 10 inches and 11 inches on the "all-flow, silty-water" plots and between 3 inches and 4 inches on the "selected-flow, silty-water" plots. In Fig. 3 is shown a comparison of an "all-flow, silty-water" plot with a "clear-water" plot.

TABLE 2.—*Summary of water and silt received by plots.*

Year	Annual precipitation, in.	Treatments			
		All flows		Selected flows	
		Added water, in.	Tons of silt per acre	Added water, in.	Tons of silt per acre
1938	9.63	18	179	18	191
1939	8.35	33	353	18	47
1940	15.26	78	889	24	165
Total			1,429		403

In 1938, the first year of treatment, there were only three flows. Six-inch portions from all three were applied to the "silty-water" plots of both the "all-flow" plots and the "selected-flow" plots. For this year, therefore, the two groups are to be considered as one, and differences in yield and sediment deposit are to be ascribed to plot and block variations. With this in mind, analysis of variance revealed no significance in the differences between the yields of "silty-water" corn plots and those receiving clear water; none between yields of "silty-water" oat plots and those receiving clear water; and none between the yields of "silty-water" bean plots and those receiving only pre-

cipitation. On the other hand, highly significant differences were found to exist between the yields of the "silty-water" bean plots and those of the "clear-water" bean plots as well as between the yields of the irrigated corn and oat plots and those of the corresponding dry plots.

In the "silty-water" bean plots many of the plants died, apparently from the effects of silt on the foliage (4). It is to this reduced number of plants that the low yield of 12.5 pounds per plot (average yield of all the "silty-water" plots), as compared to 24.6 pounds in the "clear-water" plots, is attributed (Table 3).

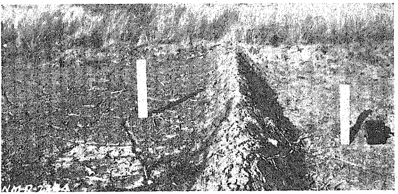


FIG. 3.—Left of dike, an "all-flow, silty-water" plot at end of third season of flooding. Right of dike, a clear water plot. The white stakes were the same height above the soil surface and were equidistant from the camera. Note cracks in the left-hand plot.

In 1939 and 1940, to keep the water and silt off of the plants, the bean rows in the flooded plots were put on the edges of ridges about 8 inches high. Thus, the water ran between alternate rows. Except in the "all-silty" plots during 1940, when the furrows were completely filled with sediment, the measure proved successful.

After the crops had been planted in 1939 the first moisture came July 28 as a rain of 0.96 inch and a flooding. This flooding was followed closely by two more, one on July 29 and the second on August 2. These three flows deposited about an inch and a half of sediment. Because of the rain on July 28, none of these flows was put on the "selected-flow" plots.

The corn, having been planted in the moist soil underlying the 3- or 4-inch layer of dry soil, was about 2 feet tall on July 28. The beans and oats had not had sufficient moisture to cause germination. Since in the bean plots most of the sediment was deposited between the ridges, emergence was not appreciably affected and a good stand was obtained. The lateness of germination, however, allowed insufficient time for the crop to mature. The oats were unable to come through the newly deposited sediment except in those places where the layer cracked. This resulted in a very thin stand in the "all-silty" plots. The consequent reduction in yield of oat hay, as compared to the

other irrigated treatments, was highly significant. The difference between the average yield of oat hay of the "all-silty" plots and that of the dry plots is not significant. Among the 1939 corn yields, the only average which is significantly different from the others is that of the dry plots. This difference is highly significant.

TABLE 3.—*Summary of crop yields from controlled plots.*

Water treatment	Year	Oats				Corn		Beans	
		Average per plot, lbs.		Average per acre		Average per plot	Average per acre	Average per plot, lbs.	Average per acre, lbs.
		Hay	Grain	Hay, lbs.	Grain, bu.	Grain, lbs.	Grain, bu.		
Rainfall	1938	9.0	2.5	850	7	12.9	15	10.2	910
	1939	5.8	0	550	0	2.5	3	0	0
	1940	10.7	0	1,000	0	10.8	13	5.7	510
All silty	1938	48.8	15.5	4,560	47	20.7	25	8.7	760
	1939	7.3	0	680	0	42.5	50	0	0
	1940	34.0	10.9	3,200	32	61.3	72	0	0
Selected silty	1938	61.4	17.5	5,760	51	37.0	43	16.3	1,450
	1939	25.4	0	2,390	0	40.8	48	0	0
	1940	32.0	9.3	3,010	28	67.1	79	32.8	2,930
All clear	1938	55.9	17.9	5,260	53	33.5	39	24.4	2,180
	1939	29.7	0	2,790	0	48.6	57	0	0
	1940	38.0	9.5	3,580	28	61.1	72	32.4	2,890
Selected clear	1938	49.4	17.5	4,640	51	30.9	36	24.8	2,210
	1939	16.9	0	1,590	0	37.0	43	0	0
	1940	31.0	7.3	2,910	21	65.0	76	33.7	3,010

Of the average yields of all three crops in 1940, only those of the dry plots and that of the "all-silty" bean plots are significantly different from the yields of other treatments.

As may be seen from Table 3, no beans were harvested from the "all-silty" plots in 1940. The plants of this treatment did well until the furrows became so filled with sediment that subsequent irrigations submerged the tops of the plants. By harvest time the plants were all dead. Whether this effect is a result of poor aeration or of the silt and water on the tops is not known. It is planned to investigate this further.

The effect of putting the beans on ridges, when the furrows are not filled in, is apparent from a comparison of the average yields of the "selected-flow" plots in 1938, when there were no ridges, with those of 1940. During these two years the "selected silty" plots received comparable amounts of sediment, 191 tons per acre in 1938 compared to 165 tons per acre in 1940, and only 6 inches more water during the latter year. The average yields for the "silty-" and the "clear-water"

plots of this group in 1938 were, respectively, 16.3 and 24.8 pounds per plot. In 1940 these same treatments averaged, respectively, 32.8 and 33.7 pounds per plot. In the former case the difference is significant; in the latter, it is not.

During the summer of 1939 and again in 1940, there were times when flows followed each other in such rapid succession that water stood on the "all-silty" plots for a long as 10 to 12 days at a time. This seemed to produce no harmful effect on either the appearance or the yield of the corn and the oats. Soil moisture determinations made on the soil of a corn plot upon which 2 inches of water were still standing 5 days after flooding indicated that the soil below the first 6 inches was not saturated. It seems evident, therefore, that, since the upper 6 inches of soil were made up of the current year's deposit of sediment, the most of the corn roots were growing in unsaturated soil. This explanation is invoked to account for the lack of effect on the yield.

The hampering of percolation by the deposited sediment does not seem to have affected the rate of absorption of the "all-silty" plots in the succeeding spring. During the pre-planting season of 1941, four 6-inch applications were made on all of the flooded plots. The silty water in these instances was relatively clear, 1% to less than 5% sediment by weight. No attempt was made to time the percolation of the first three floodings since the ground had been disturbed by spading. After 18 inches of water had been applied, however, it was assumed that the soil had settled enough to make the times of percolation valuable; and the percolation of the fourth application was timed. Analysis of the resulting data failed to show that the water took a significantly longer time to disappear from the "all-silty" plots than from the plots of the other treatments.

The sediment content of the arroyo water put on the plots, as determined by averaging the samples taken from the aliquot reservoirs after each flow, has ranged from 1.0% by weight to 29.2%. The average for all 24 of the flows applied to the "all-silty" plots during the 3 years of treatment is 8.5%; that for the 12 selected flows, 4.8%. These sediments have been relatively high in the finer fractions. The clay fraction (<5 microns) has ranged from 40 to 75% of the sediment load, with the average being well over 50%.

During each of the seasons of study it has been noted that the amount and kind of sediment carried by the water greatly affects the rate of percolation; water carrying large quantities of the finer soil fractions will lie on the plots for several days, whereas that from a succeeding, but relatively clear, flow will disappear in several hours. Wide cracks form in the sediment layer after a few days of drying (Fig. 3). These, too, facilitate penetration.

Samples for soils determinations are taken in the spring before planting and hence the data reflect the conditions from the previous year's treatment. Thus, the 1938 data represent conditions at the outset of the experiment; those for 1939, 1940, and 1941 reflect, respectively, the effects of 1, 2, and 3 years of treatment.

Methods used for making chemical and bacterial determinations were those given by Emerson (3). The pipette method of Olmstead,

Alexander, and Middleton (7) has been used for the mechanical analyses.

Except in soil texture, no great changes have occurred as a direct result of treatment (Table 4). The total numbers of bacteria have varied widely from year to year within the same treatment. In the dry plots the original bacterial count was about 852,000 per gram of dry soil. In 1939 this number had dropped to 629,000; in 1940 it was 2,110,000; but in 1941 it was down again to 1,079,000. Similar fluctuations in the yearly averages have been observed in the other treatments, except that they have been less pronounced in the "clear-water, selected-flow" plots.

The quantity of nitrate has progressively decreased in the soil of all plots, except those receiving selected flows of silty water. In these, following an initial decrease after 1 year of treatment, the soil nitrate has remained essentially the same.

The nitrifying power, as measured by percentages of ammonium nitrogen converted to nitrate nitrogen, has shown no consistent changes from the effects of different treatments.

TABLE 4.—*Summary of soil characteristics in the 1/100-acre experimental crop plots, 1938–41, all data being averages of the four replications.*

Treatment	Year	Mechanical analysis, %*			Total soluble salt, p.p.m.	Nitrate nitrogen, p.p.m.	Nitrifying power (percentage NH_3 converted), %	Bacteria per gram of soil, millions	pH	Organic matter, %
		Sand	Silt	Clay						
All silty	1938	68.0	13.7	18.3	1,010	13	74	1.20	8.9	1.16
	1939	50.6	19.8	19.5	—	9	86	0.80	—	—
	1940	29.2	27.9	42.9	—	8	81	2.00	—	—
	1941	13.5	35.4	51.1	1,360	3	85	0.54	8.6	1.21
Selected silty	1938	65.5	14.9	19.6	1,080	13	79	1.30	8.9	1.36
	1939	53.0	19.5	27.5	—	8	86	0.60	—	—
	1940	52.4	21.0	26.6	—	8	82	3.20	—	—
	1941	33.6	27.1	39.3	1,230	8	88	1.87	8.7	1.38
All clear	1938	66.0	14.8	19.2	1,050	13	80	1.10	8.8	1.15
	1939	66.7	14.4	18.9	—	10	85	0.75	—	—
	1940	68.0	15.3	16.7	—	8	82	2.57	—	—
	1941	65.5	15.4	19.1	1,100	4	83	1.63	8.6	1.24
Selected clear	1938	67.0	14.3	18.7	1,130	16	78	1.20	8.8	1.24
	1939	66.2	15.1	18.7	—	10	84	1.00	—	—
	1940	66.4	14.9	18.7	—	8	80	2.90	—	—
	1941	67.3	14.8	17.9	1,050	6	78	2.51	8.8	1.24
Rainfall	1938	57.4	18.1	24.5	1,240	8	68	0.85	8.6	0.80
	1939	—	—	—	—	4	81	0.63	—	—
	1940	62.0	16.4	21.6	—	7	83	2.11	—	—
	1941	61.5	17.0	21.5	850	2	84	1.08	8.7	0.76

*Sand, 2.0 to 0.05 mm; silt, 0.05 to 0.005 mm; clay, <0.005 mm.

Although no systematic studies have been made, samples of flood-water and of the sediment deposited have shown that, while the nitrifying power of the sediment is low, the bacterial numbers are high. The results from these samples are typified by the data shown in Table 5. The data indicate that despite the small numbers (20,000 to 600,000, depending on type of soil and vegetation) of bacteria per gram in the soil of the contributing drainage areas, the runoff from these areas carries large numbers per unit volume and per gram of dry sediment. These results are in accord with those of the more extensive work of Wilson and Schubert (9).

TABLE 5.—*Bacterial activity in flood water and deposits.*

Description of sample	Silt by weight, %	Total bacteria per gram dry soil	Nitrifying power, %
Water sampled at peak of flow	9.50	5,320,000	—
Subsiding stages of above flow	5.46	7,530,000	—
The end of the above flow	4.60	10,700,000	—
Sediment deposit from plot after percolation	—	22,800,000	17.2

From the studies on the flooded plots it appears that neither the large numbers of bacteria in the runoff nor the low nitrifying power of the deposited sediment has permanently affected the number of soil bacteria or the nitrifying power of the soil in the plots, since by the following spring the values for both have assumed approximately the same magnitudes as were originally observed.

As would be expected from irrigating with water carrying sediment high in the finer soil factions, the proportion of sand has shown a marked decrease both in the "all-flow, silty-water" plots and in those receiving selected flows of silty water. Thus, the sand in the former set of plots has dropped from 68% in 1938 to 14% in the spring of 1941. In the latter set the drop has been from 65% originally to 34% after 3 years of treatment. The colloids (<2 microns) during the same period have increased from 15 to 40% in the "all-silty" plots and from 16 to 30% in the "selected-silty" plots. Neither the "clear-water" nor the dry plots have changed in these respects.

At the close of the flooding season in 1940 percolation rates were taken for each of the irrigated plots. As with most percolation determinations, results were highly variable within treatments. The treatment averages, however, show the general trend (Table 6).

TABLE 6.—*Percolation of 3 inches of clear water in flooded plots after the flooding season.*

	All clear, min.	Selected clear, min.	All silty, min.	Selected silty, min.
Dry-run	117	66	160	75
Wet-run	347	217	540	179

Alexander, and Middleton (7) has been used for the mechanical analyses.

Except in soil texture, no great changes have occurred as a direct result of treatment (Table 4). The total numbers of bacteria have varied widely from year to year within the same treatment. In the dry plots the original bacterial count was about 852,000 per gram of dry soil. In 1939 this number had dropped to 629,000; in 1940 it was 2,110,000; but in 1941 it was down again to 1,079,000. Similar fluctuations in the yearly averages have been observed in the other treatments, except that they have been less pronounced in the "clear-water, selected-flow" plots.

The quantity of nitrate has progressively decreased in the soil of all plots, except those receiving selected flows of silty water. In these, following an initial decrease after 1 year of treatment, the soil nitrate has remained essentially the same.

The nitrifying power, as measured by percentages of ammonium nitrogen converted to nitrate nitrogen, has shown no consistent changes from the effects of different treatments.

TABLE 4.—*Summary of soil characteristics in the 1/100-acre experimental crop plots, 1938–41, all data being averages of the four replications.*

Treatment	Year	Mechanical analysis, %*			Total soluble salt, p.p.m.	Nitrate nitrogen, p.p.m.	Nitrifying power (percentage NH_3 converted), %	Bacteria per gram of soil, millions	pH	Organic matter, %
		Sand	Silt	Clay						
All silty	1938	68.0	13.7	18.3	1,010	13	74	1.20	8.9	1.16
	1939	50.6	19.8	19.5	—	9	86	0.80	—	—
	1940	29.2	27.9	42.9	—	8	81	2.00	—	—
	1941	13.5	35.4	51.1	1,360	3	85	0.54	8.6	1.21
Selected silty	1938	65.5	14.9	19.6	1,080	13	79	1.30	8.9	1.36
	1939	53.0	19.5	27.5	—	8	86	0.60	—	—
	1940	52.4	21.0	26.6	—	8	82	3.20	—	—
	1941	33.6	27.1	39.3	1,230	8	88	1.87	8.7	1.38
All clear	1938	66.0	14.8	19.2	1,050	13	80	1.10	8.8	1.15
	1939	66.7	14.4	18.9	—	10	85	0.75	—	—
	1940	68.0	15.3	16.7	—	8	82	2.57	—	—
	1941	65.5	15.4	19.1	1,100	4	83	1.63	8.6	1.24
Selected clear	1938	67.0	14.3	18.7	1,130	16	78	1.20	8.8	1.24
	1939	66.2	15.1	18.7	—	10	84	1.00	—	—
	1940	66.4	14.9	18.7	—	8	80	2.90	—	—
	1941	67.3	14.8	17.9	1,050	6	78	2.51	8.8	1.24
Rainfall	1938	57.4	18.1	24.5	1,240	8	68	0.85	8.6	0.80
	1939	—	—	—	—	4	81	0.63	—	—
	1940	62.0	16.4	21.6	—	7	83	2.11	—	—
	1941	61.5	17.0	21.5	850	2	84	1.08	8.7	0.76

*Sand, 2.0 to 0.05 mm; silt, 0.05 to 0.005 mm; clay, <0.005 mm.

Although no systematic studies have been made, samples of flood-water and of the sediment deposited have shown that, while the nitrifying power of the sediment is low, the bacterial numbers are high. The results from these samples are typified by the data shown in Table 5. The data indicate that despite the small numbers (20,000 to 600,000, depending on type of soil and vegetation) of bacteria per gram in the soil of the contributing drainage areas, the runoff from these areas carries large numbers per unit volume and per gram of dry sediment. These results are in accord with those of the more extensive work of Wilson and Schubert (9).

TABLE 5.—*Bacterial activity in flood water and deposits.*

Description of sample	Silt by weight, %	Total bacteria per gram dry soil	Nitrifying power, %
Water sampled at peak of flow	9.50	5,320,000	—
Subsiding stages of above flow	5.46	7,530,000	—
The end of the above flow	4.60	10,700,000	—
Sediment deposit from plot after percolation	—	22,800,000	17.2

From the studies on the flooded plots it appears that neither the large numbers of bacteria in the runoff nor the low nitrifying power of the deposited sediment has permanently affected the number of soil bacteria or the nitrifying power of the soil in the plots, since by the following spring the values for both have assumed approximately the same magnitudes as were originally observed.

As would be expected from irrigating with water carrying sediment high in the finer soil factions, the proportion of sand has shown a marked decrease both in the "all-flow, silty-water" plots and in those receiving selected flows of silty water. Thus, the sand in the former set of plots has dropped from 68% in 1938 to 14% in the spring of 1941. In the latter set the drop has been from 65% originally to 34% after 3 years of treatment. The colloids (<2 microns) during the same period have increased from 15 to 40% in the "all-silty" plots and from 16 to 30% in the "selected-silty" plots. Neither the "clear-water" nor the dry plots have changed in these respects.

At the close of the flooding season in 1940 percolation rates were taken for each of the irrigated plots. As with most percolation determinations, results were highly variable within treatments. The treatment averages, however, show the general trend (Table 6).

TABLE 6.—*Percolation of 3 inches of clear water in flooded plots after the flooding season.*

	All clear, min.	Selected clear, min.	All silty, min.	Selected silty, min.
Dry-run	117	66	160	75
Wet-run	347	217	540	179

Alexander, and Middleton (7) has been used for the mechanical analyses.

Except in soil texture, no great changes have occurred as a direct result of treatment (Table 4). The total numbers of bacteria have varied widely from year to year within the same treatment. In the dry plots the original bacterial count was about 852,000 per gram of dry soil. In 1939 this number had dropped to 629,000; in 1940 it was 2,110,000; but in 1941 it was down again to 1,079,000. Similar fluctuations in the yearly averages have been observed in the other treatments, except that they have been less pronounced in the "clear-water, selected-flow" plots.

The quantity of nitrate has progressively decreased in the soil of all plots, except those receiving selected flows of silty water. In these, following an initial decrease after 1 year of treatment, the soil nitrate has remained essentially the same.

The nitrifying power, as measured by percentages of ammonium nitrogen converted to nitrate nitrogen, has shown no consistent changes from the effects of different treatments.

TABLE 4.—*Summary of soil characteristics in the 1/100-acre experimental crop plots, 1938–41, all data being averages of the four replications.*

Treatment	Year	Mechanical analysis, %*			Total soluble salt, p.p.m.	Nitrate nitrogen, p.p.m.	Nitrifying power (percentage NH_3 converted), %	Bacteria per gram of soil, millions	pH	Organic matter, %
		Sand	Silt	Clay						
All silty	1938	68.0	13.7	18.3	1,010	13	74	1.20	8.9	1.16
	1939	50.6	19.8	19.5	—	9	86	0.80	—	—
	1940	29.2	27.9	42.9	—	8	81	2.00	—	—
	1941	13.5	35.4	51.1	1,360	3	85	0.54	8.6	1.21
Selected silty	1938	65.5	14.9	19.6	1,080	13	79	1.30	8.9	1.36
	1939	53.0	19.5	27.5	—	8	86	0.60	—	—
	1940	52.4	21.0	26.6	—	8	82	3.20	—	—
	1941	33.6	27.1	39.3	1,230	8	88	1.87	8.7	1.38
All clear	1938	66.0	14.8	19.2	1,050	13	80	1.10	8.8	1.15
	1939	66.7	14.4	18.9	—	10	85	0.75	—	—
	1940	68.0	15.3	16.7	—	8	82	2.57	—	—
	1941	65.5	15.4	19.1	1,100	4	83	1.63	8.6	1.24
Selected clear	1938	67.0	14.3	18.7	1,130	16	78	1.20	8.8	1.24
	1939	66.2	15.1	18.7	—	10	84	1.00	—	—
	1940	66.4	14.9	18.7	—	8	80	2.90	—	—
	1941	67.3	14.8	17.9	1,050	6	78	2.51	8.8	1.24
Rainfall	1938	57.4	18.1	24.5	1,240	8	68	0.85	8.6	0.80
	1939	—	—	—	—	4	81	0.63	—	—
	1940	62.0	16.4	21.6	—	7	83	2.11	—	—
	1941	61.5	17.0	21.5	850	2	84	1.08	8.7	0.76

*Sand, 2.0 to 0.05 mm; silt, 0.05 to 0.005 mm; clay, <0.005 mm.

Although no systematic studies have been made, samples of flood-water and of the sediment deposited have shown that, while the nitrifying power of the sediment is low, the bacterial numbers are high. The results from these samples are typified by the data shown in Table 5. The data indicate that despite the small numbers (20,000 to 600,000, depending on type of soil and vegetation) of bacteria per gram in the soil of the contributing drainage areas, the runoff from these areas carries large numbers per unit volume and per gram of dry sediment. These results are in accord with those of the more extensive work of Wilson and Schubert (9).

TABLE 5.—*Bacterial activity in flood water and deposits.*

Description of sample	Silt by weight, %	Total bacteria per gram dry soil	Nitrifying power, %
Water sampled at peak of flow	9.50	5,320,000	—
Subsiding stages of above flow	5.46	7,530,000	—
The end of the above flow	4.60	10,700,000	—
Sediment deposit from plot after percolation	—	22,800,000	17.2

From the studies on the flooded plots it appears that neither the large numbers of bacteria in the runoff nor the low nitrifying power of the deposited sediment has permanently affected the number of soil bacteria or the nitrifying power of the soil in the plots, since by the following spring the values for both have assumed approximately the same magnitudes as were originally observed.

As would be expected from irrigating with water carrying sediment high in the finer soil factions, the proportion of sand has shown a marked decrease both in the "all-flow, silty-water" plots and in those receiving selected flows of silty water. Thus, the sand in the former set of plots has dropped from 68% in 1938 to 14% in the spring of 1941. In the latter set the drop has been from 65% originally to 34% after 3 years of treatment. The colloids (<2 microns) during the same period have increased from 15 to 40% in the "all-silty" plots and from 16 to 30% in the "selected-silty" plots. Neither the "clear-water" nor the dry plots have changed in these respects.

At the close of the flooding season in 1940 percolation rates were taken for each of the irrigated plots. As with most percolation determinations, results were highly variable within treatments. The treatment averages, however, show the general trend (Table 6).

TABLE 6.—*Percolation of 3 inches of clear water in flooded plots after the flooding season.*

	All clear, min.	Selected clear, min.	All silty, min.	Selected silty, min.
Dry-run	117	66	160	75
Wet-run	347	217	540	179

Owing probably to their having received less water in the late summer and fall, the "selected-flow" plots have been worked more by pocket gophers than have the "all-flow" plots; and during 1940, the "selected-silty" plots were more heavily infested than were the corresponding "clear-water" plots. The percolation data from four of the "selected-silty" plots from which the water was known to have drained off through gopher burrows were excluded from the average. There may have been undetected burrows under some of those whose data were included. It is to this possible circumstance that the much higher average percolation rate of the "selected-silty" plots is tentatively ascribed.

SUMMARY AND CONCLUSIONS

Corn, beans, and oats have been grown under two methods of flood irrigation. The following are the results after 3 years of treatment:

1. Corn yields from plots watered with silty water have not been significantly different from those of plots similarly watered with clear water. Corn yields from plots receiving only precipitation have been lower by highly significant differences.
2. The yields of oats have been significantly affected by sediment only when the deposit occurred before germination of the grain in quantities sufficient to stifle emergence of the seedlings.
3. Heavy silting killed out part or all of the bean plants. Placing the bean rows on ridges and selecting flows for low sediment content avoided this difficulty.
4. Yields from plots watered with flows selected for timeliness and low sediment content have not differed from those of plots watered at the same time with clear water. The sediment from these selected flows has raised the surface of the plots 3 to 4 inches in 3 years, whereas the surface of the plots receiving all flows has been raised 10 to 11 inches during the same period.
5. Application of 18 inches of water in 1939 and of 24 inches in 1940 in the "selected-flow" plots as compared to 36 inches in 1939 and 78 inches in 1940 in the "all-flow" plots produced no significant difference among the corn yields.
6. Marked increases in the clay fraction have occurred in the soils of all plots receiving silty water.
7. No great changes have occurred in the bacterial and chemical characteristics of the soil.

Although the experiment has not been continued long enough to permit the drawing of conclusions or the making of recommendations, certain points are indicated tentatively by the results of the first 3 years. From the markedly higher yields of corn and oats in the irrigated plots and the comparatively small accumulation of sediment in those plots receiving selected flows, the writers are led to the tentative conclusion that good crops may be obtained by irrigating from the relatively clearer of the intermittent arroyo flows and at the same time the land surface will not be raised to the extent of

making continued cultivation of the land impracticable. On the other hand, while yields of corn and oats from the plots watered with every flow have thus far not differed significantly from those of the plots receiving selected flows, the amount of sediment deposited on these plots has been so great as to indicate that continued use of the practice would probably be impracticable except in situations where the raising of the soil surface is not a factor to be considered. This brings up the question of desilting. While this has not been tried in the present experiment, our observations of the rapidity with which basins behind diversion dams are filled lead us to believe that the cost of maintaining desilting basins would be prohibitive.

LITERATURE CITED

1. Bingham, G. H., and Monson, O. W. Flood irrigation. Montana Ext. Circ. 84. 1937.
2. Bryan, Kirk. Flood-water farming. Geog. Rev., 19:444–456. 1929.
3. Emerson, Paul. Soil characteristics: A Field and Laboratory Guide. New York: McGraw-Hill. 1935.
4. Forbes, R. H. Irrigating sediments and their effects upon crops. Ariz. Agr. Exp. Sta. Bul. 53. 1906.
5. Hough, Jack L., and Flaxman, Elliott M. Advance report on the sedimentation survey of the Bennett Irrigation and Silting Basin, Wilson Creek, Washington. U. S. D. A. SCS-SS-27. Mimeo. 1938.
6. Monson, O. W., and Quesenberry, V. R. Range improvement through conservation of flood water. Report of progress. Mont. Agr. Exp. Sta. Bul. 380. 1940.
7. Olmstead, L. B., Alexander, L. T., and Middleton, H. E. A pipette method of mechanical analysis of soils based on improved dispersion procedure. U. S. D. A. Tech. Bul. 170. 1930.
8. Stewart, Guy R. Conservation in Pueblo agriculture. Sci. Monthly, 51:201–220; 329–340. 1940.
9. Wilson, J. K., and Schubert, H. J. The microflora in the soil and in the runoff from the soil. Jour. Amer. Soc. Agron., 32:833–841. 1940.

ENZYMATIC VS. MICROBIAL CONCEPTS OF UREA HYDROLYSIS IN SOILS[1]

JOHN P. CONRAD[2]

TRANSFORMATIONS of organic materials in soils have been almost universally assumed by soil scientists to be brought about by the direct action of microorganisms. According to this concept if any such transformation occurs in soils some microorganisms must be directly responsible. Recently, considerable evidence (2, 4, 5)[3] has been collected which strongly suggests that some soil transformations at least are catalytic and indeed enzymatic in nature. Thus, in the presence in excess of the antiseptic toluene, a standarized percolation procedure secured a rather uniform rate of reduction in the concentrations of urea solutions percolated through some soils after the first percolates had been collected. Such uniform urea-splitting activities in the presence of toluene can be taken as direct evidence of enzyme behavior. Although no urease-like activity has been eluted from any of these soils, still other evidence (3) points to the presence in soils of enzymes or similar substances which are urease-like in their behavior.

In addition to these soils possessing a rather uniform urea-splitting ability, other soils exhibited, by the use of the same procedure, rapidly accelerated rates of urea decomposition as the percolations were continued. It is more difficult to interpret the behavior of these latter soils with simple enzyme behavior. A number of responsible microbiologists have informally suggested to the writer that microorganisms especially resistant to toluene or entirely indifferent to it might be present and by multiplying rapidly in its presence cause the accelerated urea decomposition noted. If this microbial concept were validated for these accelerated activities, it might easily suffice to explain the uniform activities of the first soils mentioned. This paper presents additional evidence attempting to determine whether microorganisms or enzyme-like substances are responsible for urea hydrolysis in the presence of toluene and other antiseptics.

PROCEDURE

Although the standardized procedure for conducting the percolations has been previously described (4), a brief resume is given here. For each unit percolation a 400-gram charge of dry soil was placed in a glass percolator provided with a suitable filter plate and paper. Successive portions of a standard urea solution (the initial portion large enough in volume to bring the soil mass to the verge of dripping, e.g., 150 cc, and later ones smaller and equal, e.g. 75 cc) were added at regular time intervals, generally either every 12 hours or every 24 hours unless

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Most of the analyses reported herein were kindly carried out by Mr. William Fishman, technician, and the bacterial counts by Mr. I. E. Vanoni, research assistant in the Division of Agronomy. Received for publication July 6, 1942.

[2]Associate Professor of Agronomy and Associate Agronomist in the Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 1113.

otherwise noted. Percolations were carried out generally in a constant temperature room at approximately 30°C unless otherwise stated. The successive percolates were caught separately and analyzed for the residual urea by the Marshall urease method essentially as described by Hawk and Bergeim (8), except that the indicator, brom-phenol-blue, was used instead of methyl orange. Adsorption of urea by the soil colloids was weak but definite (2). Its effect was not in evidence much beyond the second percolate caught. For each of the later percolates, the reduction from the initial concentration[4] of the percolating urea solution was taken as a measure of the urea-splitting activity in the soil for that particular percolate. Relying on accumulated data, part of which has been published (3), it is believed that substantially all of the urea disappearing from the later percolates has been hydrolyzed to $(NH_4)_2CO_3$, with the NH_4 ion being subsequently retained by the soil through well-known reactions with the colloids.

In case a percolation was to be conducted in the presence of the antiseptic, toluene, from 5 to 10 cc of liquid was added to and thoroughly mixed with the dry soil before being placed in the percolator. Toluene in excess of solution saturation was also added to each percolating urea solution for each percolation conducted in the presence of toluene.

Some of the experiments required soil preheated to inactivate any urease-like catalysts in the soil. To accomplish this pretreatment, dry soil was placed in crocks, wet with distilled water, and, with the crocks covered, heated at approximately 85°C for at least 48 hours. Subsequently, the soil was dried, sieved, mixed, and stored for the experiments.

EFFECT OF VARIOUS ANTISEPTICS

If the organisms resistant or indifferent to toluene, postulated by the microbial concept, were present in soils, there should be some antiseptic which would inactivate them completely. On the other hand, a simple enzyme reaction might be little affected by any individual antiseptic unless the latter were actually injurious to it.

In the experiments initiated, the antiseptics were added to the dry soils and to the percolating urea solutions in the following amounts:

Antiseptic	Amount added to 400-gram charge of soil	Amount added to percolating urea solution
Toluene, $C_6H_5CH_3$	5 cc	0.2% by volume
Chloroform, $CHCl_3$	5 cc	0.68% by volume
Carbon disulfide, CS_2	5 cc	0.6% by volume
Potassium cyanide, KCN	4 grams	1.0% by weight
Thymol, $CH_3(C_3H_7)C_6H_3OH$	2 grams	0.1% by weight
Phenol, C_6H_5OH	2 grams	0.5% by weight

Because of the dangers from chloroform and carbon disulfide fumes, these percolations were conducted in an open shed during the summer. Maximum, minimum, and other readings of a thermometer hung near the percolators are given in Table 1.

[4]Concentrations are expressed in m.at.N/liter (milligram-atoms of nitrogen per liter).

TABLE 1.—*Temperature readings in degrees taken from a maximum-minimum thermometer hung near the percolators used in securing the data for Fig. 1.*

Kinds of temperature reading taken	Successive 75-cc percolates at 12-hour intervals						
	1	2	3	4	5	6	7
At time of collecting percolate	18	16	21.5	18.5	23	19	20
Maximum for preceding 12 hours	31	20	32.0	23.0	33	25	30
Minimum for preceding 12 hours	17	13	16.0	14.0	17	16	20

Fig. 1 gives the results of the percolations with different antispetics. Not all antiseptics have had the same effect on the urea-splitting activities of these three soils. Undoubtedly a very complex series of reactions has occurred with each of the antiseptics used. Among the many factors which may be responsible for the behavior of each of these soils in the presence of each of the antiseptics, undoubtedly the following contributed materially to the results secured: The kind of antiseptic, the action of the antiseptic on the soil and on either the enzyme-like substances or the microorganisms, and the nature

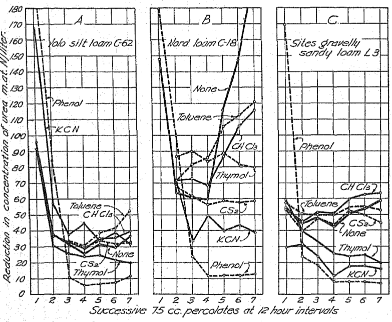


FIG. 1.—The effects of various antiseptics upon the reduction in the initial (200 m.at.N/liter) concentration of urea solutions percolated through 400-gram samples of three soils: Yolo silt loam (6), Vina loam (14), and Sites gravelly sandy loam (10). To avoid confusion of lines some of the values for the first percolates were not plotted.

and properties of the particular soil. In connection with the problem of this paper, however, certain data are of interest. All antiseptics did not give the same results with each soil. These facts alone cannot be interpreted as favoring either concept. Each antiseptic might inhibit either some special group of microorganisms or some special urease-like substance (if more than one were present) and thereby bring about the results secured. On the other hand, greater activities occurred in the presence of the antiseptics toluene and chloroform than in the absence of any antiseptic for at least a part, if not all, of the percolation period. These facts are difficult to reconcile with the concept that microorganisms are directly responsible for urea hydrolysis in soils.

EFFECTS OF SOIL PREHEATING AND OF ADDED NUTRIENTS

Soil preheated to 85°C has been found to be practically free of any urease-like activities (2). A small amount of untreated soil mixed with a percolator charge (400 grams) of preheated soil should adequately inoculate the latter with all strains of microorganisms found in the original untreated soil without any material additions of active urease-like substances. Moreover, the addition of nutrients especially favorable to the development of urea organisms should further enhance with continued percolation the numbers and activities of these organisms and consequently the rate of urea hydrolysis. Preheated soil inoculated with a small amount of untreated soil and with added nutrients and toluene should be most favorable for these organisms and at the same time preclude any but the smallest contributions to urea hydrolysis from urease-like substances. A rapidly accelerated urea hydrolysis under these experimental conditions, therefore, would constitute strong evidence of the presence of organisms capable of splitting urea in soil antisepticized with toluene. On the other hand, the lack of such an urea hydrolysis would cast strong doubt on the presence of the postulated organisms in the soil.

A Yolo silt loam, C-62, was used in these experiments because the untreated lot of this soil had shown a typical rapidly accelerated urea-decomposing activity. Preheated lots had shown but very little, if any, activity. In preliminary trials the preheated lot of this soil exhibited impaired permeability by the end of the percolation period. In consequence, 400 grams of dry sand were mixed with 400 grams of the silt loam mixtures (preheated plus untreated). Toluene as an antiseptic was then mixed with each soil-sand mixture. After the percolators had been charged, 200 cc of the percolating solution containing toluene in excess of solution saturation, and containing 200 m. at. N/liter as urea, were added to each percolator to wet the soil and bring it to the verge of dripping. Subsequently successive 90-cc portions of solution were added at 24-hour intervals. Calcium citrate, where applied, was mixed at the rate of 1 gram with each 800 grams of the dry soil-sand mixture before charging the percolator. The beef extract, where employed, was dissolved in the urea solution before the percolation was started. The soil-sand mixtures, nutrients supplied, and the reductions in concentrations of percolating urea solutions are given in Table 2.

With each soil-sand mixture, percolators containing calcium citrate gave data suggesting greater activities than did those receiving no nutrients. With soil-sand mixtures containing little or no untreated soil, the data suggested higher activity for the beef extract percolates than for those with no nutrients. With the higher amounts of untreated soil in the mixtures, however, the reverse seemed true.

After the percolations, data from which are reported in Table 2, had been finished, preliminary counts of urea bacteria were made on soil samples taken aseptically from the respective percolators. Medium 47, urea bouillon agar as given by Fred and Waksman (7), was used for plating. The trends were, in general, toward higher numbers of bacteria the greater the amount of previously untreated soil present in the mixtures regardless of the nutrients previously added to the soil mixtures. In a parallel series of plates, a small volume of toluene was inserted in each inverted Petri dish below the agar medium. No detectable colonies developed on these plates until a few days after the toluene had evaporated.

TABLE 2.—*Reduction in the initial (200 m.at. N/liter) concentration of urea solution percolated in the presence of toluene through various mixtures of untreated and preheated Yolo silt loam and an equal weight of sand and in the presence of different microbial nutrients.*

Pre-heated soil, grams	Un-heated soil, grams	Sand, grams	Nutrient material added	Reduction in concentration of urea in successive 90-cc percolates at 24-hour intervals*					
				1	2	3	4	5	6
400	0	400	None	58	6	4	1	2	3
			Ca citrate	60	15	5	5	6	3
			Beef extract	64	16	6	6	4	11
380	20	400	None	48	10	4	2	4	0
			Ca citrate	68	13	6	6	7	4
			Beef extract	51	20	6	10	7	7
260	140	400	None	74	25	24	24	27	28
			Ca citrate	68	29	24	25	32	30
			Beef extract	100	24	25	27	22	13
0	400	400	None	105	55	74	98	125	134
			Ca citrate	87	66	92	119	145	142
			Beef extract	80	46	53	77	77	83

*Concentration values in m.at. N/liter.

Comparison of the titrations of percolates from the same soil-sand mixtures but with and without the special nutrients beef extract or calcium citrate disclosed the possibility that some of the residual urea might have been transformed to ammonium carbonate after the percolates had collected in the receiving flasks, especially if the toluene had evaporated. With toluene gone from the receiving flasks any microorganisms would have ample opportunity to multiply sufficiently to transform considerable urea before analyses for urea could be made. The percolates from the series containing either beef

extract or calcium citrate would offer more favorable conditions for bacterial growth and resulting urea hydrolysis than percolates from the series receiving no special nutrients. To reduce this source of experimental error to a minimum during subsequent percolations, a crystal of the antiseptic thymol was kept in each receiving flask.

It seemed desirable to repeat the calcium citrate and no nutrient series for the mixtures containing the greater amounts of untreated soil. These percolations were conducted in triplicate with thymol added to the receiving flasks. The data secured are plotted in Fig. 2. The data from Table 2 secured from the preheated soil-sand mixtures are also included in Fig. 2 to serve as a control.

If microorganisms had been responsible for the rise in the untreated soil, the mixture of 140 grams of untreated soil with 260 grams of the preheated soil should have shown a rapidly rising activity though perhaps starting somewhat more slowly than with the untreated soil alone. With the added nutrient calcium citrate, the rise should have been even more rapid. The data of Fig. 2 show that neither of these expectations of the microbial concept was fulfilled. The untreated soil-sand mixture showed a rise typical of that of the untreated soil alone. The changes in urea-splitting activities found were more nearly related to the content of untreated soil which presumably contained a definite amount of urease-like substance or substances than to the nutrient supply favorable to microbial development.

At the finish of the replicated percolations, data for which are plotted in Fig. 2, counts for bacteria were made on plates of urea bouillon agar as before with samples of soil-sand mixtures from the respective percolators. The bacterial counts as given below are averages from triplicate percolators receiving the same treatment:

Sand, grams	Unheated soil, grams	Preheated soil, grams	Calcium citrate, grams	Bacteria number per gram
400	140	260	0	200,000
400	140	260	1	199,000
400	400	0	0	439,000
400	400	0	1	417,000

At the time the counts as reported immediately above were made, a parallel series of plates were poured, inverted, toluene added to the inverted plates, and the plates were placed in a dessicator charged with a shallow layer of toluene. After many days of incubation no visible colonies had developed.

These data certainly give little support to the microbial concept according to which microorganisms would develop in the presence of toluene to account for the acceleration of the urea-decomposing activity of the soil as percolations were continued. Under conditions which should have been highly favorable for exhibiting the presence and multiplication of the microorganisms presumably indifferent to toluene, namely, preheated soil inoculated with untreated soil and

therefore adequately inoculated with all strains of the original soil, no rapidly accelerated rise in urea-hydrolysis occurred in the presence of toluene, even when media especially favorable to urea organisms, either beef extract or calcium citrate, were added. Furthermore, no colonies developed from soils in these tests in the presence of toluene on plates of an agar medium favorable for the multiplication of urea bacteria.

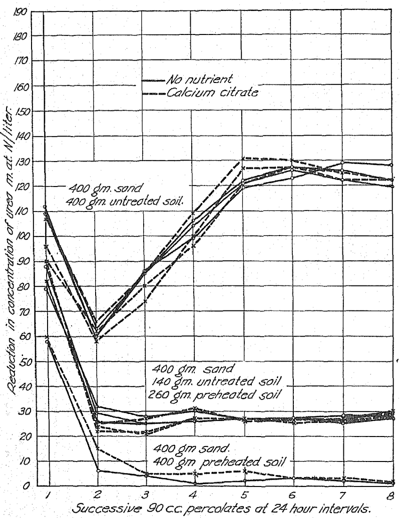


FIG. 2.—Reduction in the initial (200 m.at.N/liter) concentration of urea solutions percolated in the presence of toluene through 800 grams of various soil-sand mixtures as influenced by the amounts of untreated and preheated Yolo silt loam used and the addition of calcium citrate.

EFFECTS OF DIFFERENT TEMPERATURES

Conducting percolations at different temperatures might lead to data helping to distinguish between enzyme-like and microbial activities. Salle (11) stated that the maximum temperature for growth for saphrophitic mesophylic organisms is about 30°C with optimum temperatures from 18°C to 25°C, although the optimum of some thermophilic bacteria is as high as 55°C or even higher. Waksman (13) stated that the optimum temperature for the action of the urea bacteria is about 30°C. One organism, *Bacillus probatus*, which he listed has an optimum growth temperature from 28° to 35°C and a maximum growth temperature of 44° to 45°C. Other urea organisms are known to have maximum growth temperatures of 35°C or less. There seems to be little risk then in assuming that the maximum growth temperature is 45°C or lower for most of the urea organisms normally present in soils.

Van Slyke and Cullen (12), on the other hand, gave 55°C as the optimum temperature for soybean urease. Unless the numbers and activities of thermophilic urea bacteria would be high, conducting percolations at 50°C should serve to distinguish between enzymatic and microbial activities.

In planning the experiments, it was assumed that the coefficient for a 10°C rise in temperature was 2 for the enzymatic breakdown of urea. Other factors being equal it was expected that approximately the same figures for the urea-splitting activities would be secured if the temperature was increased 10°C and the time interval between adding successive portions of the urea solutions halved. It was more convenient, however, to vary the temperature by approximately 20°C rises and to reduce the time by quartering. Percolations were conducted with six different soils at three different temperatures with three different time intervals, and with more than one concentration for each of some of the soils employed. The differential treatments as well as the resultant effects of these on the reductions in concentrations of the percolating urea solutions are reported in Table 3.

The percolations originally planned for 10°C were conducted during January, 1941, at Davis in a well-insulated but not thermostatically controlled room. The actual temperatures varied from 7° to 15°C with a computed weighted average of 11.8°C. All soils when percolated at the two lower temperatures drained easily in the time intervals employed. Those percolated at 50°C and with intervals of only 3 hours between percolates did not have sufficient time to drain naturally. In consequence, suction was applied continuously. Undoubtedly, on account of the lower surface tension of water at this temperature and the use of suction, the amount of solution in contact with the soil might have been somewhat less at 50°C than those amounts in contact with the soil at the lower temperatures of 11.8° and 30°C.

Without exception there were greater withdrawals of urea from solution in the first percolates the lower the temperature of percolation. No explanation is offered for this behavior. In general, for the second and third percolates and in some cases the fourth percolate,

the withdrawals were higher for those conducted at the lower temperatures.

TABLE 3.—*Reductions in concentrations of urea solutions percolated in the presence of toluene through 400-gram portions of different unheated soils as influenced by temperature of percolation and time intervals between adding successive portions of solutions.*

Soil	Concentration of urea	Temperature, °C	Time interval, hours	Reduction in concentration of urea in successive 75-cc percolates*					
				1	2	3	4	5	6
Vina loam C-33 (9)	100	11.8	48	76	62	67	63	67	83
		30.0	12	65	55	55	58	64	78
		50.0	3	55	50	52	49	53	57
Maywood silty clay loam C-34 (9)	100	11.8	48	47	13	9	3	3	1
		30.0	12	20	5	4	6	7	5
		50.0	3	19	1	0	0	0	0
Yolo silt loam C-62 (6)	100	11.8	48	69	43	47	41	42	48
		30.0	12	64	34	37	41	52	66
		50.0	3	50	30	35	35	38	49
C-62	200	11.8	48	127	56	56	48	53	68
		30.0	12	106	46	49	59	78	93
		50.0	3	81	39	41	47	50	49
C-62	400	11.8	48	231	70	72	65	74	87
		30.0	12	185	61	61	75	96	116
		50.0	3	149	42	58	52	65	68
Yolo fine sandy loam, C-68 (6)	100	11.8	48	39	26	25	17	17	16
		50.0	3	18	12	11	13	11	10
Huerhuero sandy loam, C-81 (1)	100	11.8	48	35	38	38	35	39	42
		30.0	12	22	28	28	30	31	32
		50.0	3	5	19	12	10	13	17
Nacimiento clay loam, C-82 (1)	200	11.8	48	159	96	107	103	113	118
		30.0	12	108	88	96	91	88	88
		50.0	3	77	61	71	67	71	74
C-82	400	11.8	48	261	127	127	125	120	148
		30.0	12	198	126	127	131	134	120
		50.0	3	162	93	79	80	78	83

*Concentration values in m.at. N/liter.

Van Slyke and Cullen (12) gave 1.91 as the average temperature coefficient for urease activity for a 10°C rise between 10° and 50°C. For a rise of 20°C we would expect a temperature coefficient of $(1.91)^2$, or 3.65. As the time interval between adding successive portions was only one-fourth with each rise of 20°C, we should expect that the values secured and reported in Table 3 at 50°C would be about 0.91 of those at 30°C and those at 30°C would be $\frac{(1.91)^{1.82}}{4}$, or about 0.81 of those at 11.8°C. Making some allowance for normal variability

and except for soil C-34 these values were approached for the second, third, and in some cases the fourth percolates. With some of the soils values for the fifth and sixth percolates rose more rapidly for the 30°C temperature than for the other temperatures. By varying the temperature and the time intervals as has been described above, it is not to be expected that other important factors would be proportionately affected. Thus the lower viscosity and lower surface tension of water at each higher temperature should allow more rapid percolation and more complete drainage of the solution from the soil. But these factors were more than counterbalanced by the effect of reducing the time interval between the several percolates, as suction was required to complete drainage in the percolations at 50°C and 3-hour intervals between percolates.

At 50°C much urea hydrolysis took place in all soils except C-34. These data in themselves would seem to invalidate the microbial concept unless thermophilic urea-decomposing organisms were present in these soils in numbers and efficiency approximately equal to those operative at 30°C. To throw some light on the relative numbers of organisms capable of developing at 30°C and at 50°C, bacterial counts were made from stock untreated lots of all but one of the soils reported in Table 3, parallel plates on urea bouillon agar being incubated, one series at 30°C and the other at 50°C. The following counts were secured:

Soil	Number per gram with plates incubated at	
	30° C	50° C
Maywood silty clay loam, C-34	333,000	180,000
Yolo silt loam, C-62	980,000	22,000
Yolo fine sandy loam, C-68	510,000	$<10,000$
Huerhuero sandy loam, C-81	1,130,000	75,000
Nacimiento clay loam, C-82	2,660,000	25,000

The much smaller number of microorganisms developing on the plates incubated at 50°C than at 30°C would seem to indicate insufficient thermophilic bacteria to account for the hydrolysis of urea in soils found at 50°C in the presence of toluene (Table 3).

DISCUSSION

The microbial concept calling for the rapid multiplication of microorganisms in the soil during percolation with urea solutions in the presence of toluene as a cause of the rapid acceleration of the urea-splitting activity of soils is not substantiated by the data collected in this study. The results obtained, on the other hand, strongly support the enzyme concept. It is quite evident that the enzyme action is not a simple one but is much more complex than was at first apparent.

On the basis of the data so far secured, the microbial concept is by no means completely ruled out, but the microorganisms would need

to have characteristics markedly different from those with which we are most familiar. They would need to be resistant to toluene even in excess of solution saturation and to be able to multiply effectively in its presence. They would be unable to multiply on the usual calcium citrate or beef extract media at least in the presence of toluene as no colonies developed on plates of such media in the presence of that antiseptic. At least some of the strains would need to be thermophilic. The existence of such organisms now seems remote.

The best type of evidence to support the microbial concept would be the isolation of organisms from the soil with characteristics enumerated above. If they were then inoculated into sterile soil and produced the rapidly accelerated urea-decomposing activity in the presence of toluene and were then again isolated from the soil, the microbial concept would be substantiated. Efforts to get any microorganisms to grow on plates in the presence of toluene have failed.

The best type of additional evidence to controvert the microbial concept would be the discovery of other factors adequate to account for the phenomenon of the rising urea-splitting activity with continued percolation. Investigations are in progress on several "leads" which seem hopeful in this direction.

SUMMARY

Data secured previously with many soils disclosed rapidly rising activities in splitting urea even in the presence of the antiseptic toluene, as percolations by a standard procedure were continued. In this procedure successive equal portions of a standardized urea solution were added to the soil in the respective percolators at equal time intervals. The residual urea in successive percolates was determined. These data suggested that microorganisms might, however, be causing the rise in activity by rapid multiplication, even in the presence of toluene. Experiments to distinguish between microbial and enzymelike activities were conducted.

Percolations with each of three soils in the presence of the different antiseptics disclosed activities which were far from identical. With no antiseptic were the activities completely stopped. For some one or more time intervals, the activities of each soil percolated in the presence of either chloroform or toluene were greater than where no antiseptic was used.

Percolations involving varying mixtures of preheated and untreated soil and the absence or presence of a nutrient favorable to urea bacteria (either beef extract or calcium citrate) were conducted all in the presence of toluene. Variations in activities were consistent with the amount of untreated soil (presumably containing ureaselike substances) present in the mixtures. The untreated soil with no preheated soil present was the only one to exhibit the typical rapidly rising activities despite the fact that the other mixtures in general had adequate inoculation. The addition of nutrients favorable to urea bacteria failed to accelerate the activities of the soil in the presence of toluene. Counts of bacteria on urea bouillon agar at the end of the percolations failed to disclose significant increases in numbers of organisms in soil mixtures to which calcium citrate had

been added. Parallel series of plates from the soil mixtures incubated in the presence of toluene failed to develop distinguishable colonies.

Percolations in the presence of toluene were conducted at different temperatures with six different soils, some of them with more than one concentration of urea. The time intervals between successive percolates was 48 hours for the 11.8°C temperature, 12 hours for 30°C, and 3 hours for 50°C. In general, the activities with the same soil at different temperatures was of the same order of magnitude, suggesting enzyme-like activities. Considerable activity was evidenced at 50°C above the maximum growth temperature of recognized urea bacteria. Plates for bacterial counts incubated at 50°C showed only a small fraction of the number of bacterial colonies which developed on parallel plates incubated at 30°C. Until further data to the contrary are secured, there is little or no evidence to support a microbial concept of urea hydrolysis in soils in the presence of toluene.

LITERATURE CITED

1. CARPENTER, E. J., and STORIE, R. EARLE. Soil survey of the Paso Robles area, California. U. S. D. A. Bur. Chem. and Soils, Ser. 1928, Rpt. 34. 1933.
2. CONRAD, JOHN P. Hydrolysis of urea in soils by thermolabile catalysis. Soil Sci., 49:253–263. 1940.
3. ———. The nature of the catalyst causing the hydrolysis of urea in soils. Soil Sci., 50:119–134. 1940.
4. ———. Catalytic activity causing the hydrolysis of urea in soils as influenced by several agronomic factors. Soil Sci. Soc. Amer. Proc., 5:238–241. 1940.
5. ——— and ADAMS, C. N. Retention by soils of the nitrogen of urea and some related phenomena. Jour. Amer. Soc. Agron., 32:48–54. 1940.
6. COSBY, STANLEY W., and CARPENTER, E. J. Soil survey of the Dixon area, California. U. S. D. A. Bur. Chem. and Soils, Ser. 1931, Rpt. 7. 1935.
7. FRED, E. B., and WAKSMAN, S. A. Laboratory Manual of General Microbiology. New York: McGraw-Hill Book Co. 1928.
8. HAWK, PHILIP B., and BERGEIM, OLAF. Practically physiological chemistry. Philadelphia: J. Blakiston's Son and Co. Ed. 11. 1937.
9. HOLMES, L. C., and ECKMANN, E. C. Soil survey of the Red Bluff area, California. U. S. D. A. Bur. Soils, Advance Sheets, Field Oper. 1910. 1912.
10. MANN, C. W., WARNER, J. F., WESTOVER, H. L., and FERGUSON, J. E. Soil survey of the Woodland area, California. U. S. D. A. Bur. Soils, Advance Sheets, Field Oper. 1909. 1911.
11. SALLE, A. J. Fundamental Principles of Bacteriology. New York: McGraw-Hill. 1939.
12. VAN SLYKE, D. D., and CULLEN, G. E. The mode of action of urease and of enzymes in general. Jour. Biol. Chem., 19:140–180. 1914.
13. WAKSMAN, S. A. Principles of Soil Microbiology. Baltimore: Williams and Wilkins. Ed. 2. 1932.
14. WATSON, E. B., GLASSEY, T. W., STORIE, R. EARLE, and COSBY, S. W. Soil survey of the Chico area, California. U. S. D. A. Bur. Chem. and Soils, Ser. 1925, Rpt. 4. 1929.

ANALYSIS OF NONHERITABLE VARIATIONS IN SEED SET UNDER BAG AMONG PLANTS OF ORCHARD GRASS, *DACTYLIS GLOMERATA* L.[1]

W. M. MYERS[2]

IN studies of ability to set seed under bag among plants of *Dactylis glomerata* L., a large amount of variation has been encountered. A knowledge of the magnitude of that variation and of the factors contributing to it is essential for interpreting data that already have been obtained. Such information is even more necessary for intelligently designing further experiments dealing with this character.

The literature dealing with heritable variations in self-fertility in orchard grass has been reviewed in another paper (8).[3] Little information is available in the literature on the extent of nonheritable variations in seed set under bag or on the factors influencing that variation. Walle (Stapledon, 13) found large variations in self-fertility for individual plants from year to year. One plant set over five times as much seed in 1922 as in 1924. Similar interannual variations were reported by Stapledon (13), Schultz (11), and Smith.[4] Schultz (11) found that the correlation coefficient determined between years ($r = .30$) only approached the 5% point. In the absence of a valid estimate of error in these cases, it is difficult to judge whether the variation between years was statistically significant.

It is the purpose of this paper to present analyses of the magnitude and nature of variations both between and within years in number of seeds per panicle set under bag among clonal lines of *Dactylis glomerata*.

MATERIALS AND METHODS

Data on number of seeds per panicle set under bag were obtained from 497 spaced plants during the summer of 1938. From these, 60 plants were selected which ranged from the highest seed set to the lowest from which an adequate inbred progeny could be obtained. The parent plants were increased vegetatively and during the fall of 1938 the parental clones and first-inbred generation (I_1) progenies were planted in the field in adjacent rows distributed at random in three replications. The methods of planting has been described in detail by Myers and Chilton (9).

The data presented in this paper were obtained from the parental clones. In 1939, four to six panicles were enclosed in a single bag on one plant in each replication of the clones. In 1940, four panicles per bag were enclosed in three bags on

[1]Contribution No. 34 of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Northeastern States. Received for publication July 13, 1942.

[2]Geneticist. The author wishes to express his appreciation to Dr. F. R. Immer, Vice-Director, Minn. Agr. Exp. Sta., University Farm, St. Paul, Minn., for valuable suggestions regarding the statistical procedures used in this paper. Dr. Immer did not see the manuscript in final form, however, and the author assumes full responsibility for any errors.

[3]Figures in parenthesis refer to "Literature Cited", p. 1123.

[4]SMITH, D. C. Controlled pollination studies in grasses. In manuscript.

each of two plants in each replicated clonal row. The larger panicles, which apparently would flower within the next two or three days, were selected for bagging as far as possible. However, in some cases where the plant had started to flower or where too few panicles were available, it was necessary to bag later and smaller panicles. As a result of winterkilling and other factors, it was possible to obtain complete data on seed set under bag on only 51 of the parental clones.

From the data obtained in 1939, it was apparent that there was considerable random variation in seed set. At least four factors could have contributed to this variability, *viz.*, (a) variations in size of panicle and, consequently, in number of florets per panicle; (b) injury to the culms in some cases since cotton was not wrapped around them at the base of the bag; (c) variations in the number of panicles enclosed in each bag; and (d) differences in date of flowering among panicles on the same plant, particularly since the earlier panicles are always larger than those that mature later. The effects of the first factor were eliminated insofar as possible by selection of the larger panicles on each plant. Even with this precaution, however, variations in number of florets per panicle probably were an important cause of variability in number of seeds set under bag. To test the effects of the latter three factors, a "split plot" experiment was utilized. Four of the parental clones which were known to be similar in seed-setting ability were selected and in each replication one plant was bagged in the usual manner, while on an adjacent plant the culms were wrapped with cotton at the base of the bag for protection from injury. On each of the pair of plants, four bags, enclosing 1, 2, 4, and 8 panicles, respectively, were placed on the first group of panicles to emerge and about one week later a similar series of bags was placed on a later group of panicles.

Vegetable parchment bags, $12 \times 4 \times 2$ inches, were used throughout the experiment. The bags were supported by passing a string through an eyelet which had been punched in an upper corner of the bag and tieing it around a cane stake. The plant number was written on a copper-wired wood tree label, the wire of which was used for closing the bottom of the bag. At harvest time, the panicles were left in the bag with the label attached until threshing.

When the panicles were threshed, the number of panicles and the total number of seeds produced per bag were counted, and seed set was expressed throughout the experiments as number of seeds per panicle. In the statistical treatment of the data, Fisher's (3) analysis of variance was used and values of F for P of 0.05 and 0.01 were obtained from Snedecor's (12) Table of F.

EXPERIMENTAL RESULTS

VARIATION BETWEEN YEARS

The data on number of seeds per panicle set by the 51 clones in the three years, 1938, 1939, and 1940, are shown in Table 1. One of the most striking features of these data was the extreme variation between years for most clones. Furthermore, the variation was not consistently in one direction but some clones were higher in one year while others were higher in another. The question arises whether these differences are statistically significant. The data for 1938 were based upon seed set in a single bag and, as a result, no estimate of error is available. Data were obtained from three replications of each clone in 1939 and 1940. Consequently, these data may be subjected to statistical analysis. The mean seed set of the clones ranged

TABLE 1.—*Average number of seeds per panicle set under bag on plants of 51 clones of orchard grass in 1938, 1939, and 1940.*

Clone No.	No. seeds set in				Clone No.	No. seeds set in				Clone No.	No. seeds set in			
	1938	1939	1940	Av.		1938	1939	1940	Av.		1938	1939	1940	Av.
1(19)	2	1	1	1.3	8(13)	48	28	10	28.7	1(23)	100	104	28	77.3
14(11)	4	1	2	2.3	1(8)	26	46	16	29.3	14(12)	28	167	63	86.0
13(3)	7	0	1	2.7	7(20)	57	19	16	30.7	20(11)	67	62	141	90.0
2(3)	5	8	4	5.7	6(9)	19	63	13	31.7	2(21)	134	74	67	91.7
48(172)	5	9	4	6.0	46(11)	11	38	51	33.3	2(20)	125	133	28	95.3
1(22)	2	14	3	6.3	4(20)	30	62	18	36.7	48(48)	167	126	45	112.7
48(27)	15	2	2	6.3	6(12)	46	54	19	39.7	48(92)	140	138	74	117.3
48(270)	18	1	2	7.0	8(19)	75	44	6	41.7	6(13)	120	144	94	119.3
11(18)	21	1	2	8.0	1(1)	40	40	46	42.0	4(4)	50	215	94	119.7
48(6)	18	2	5	8.3	47(22)	140	33	6	59.7	48(226)	280	75	8	121.0
18(15)	6	23	7	12.0	20(14)	82	60	43	61.7	1(12)	136	128	113	125.7
2(11)	20	16	13	16.3	42(24)	175	14	15	68.0	48(47)	160	138	80	126.0
14(13)	7	38	14	19.7	9(10)	72	50	84	68.7	47(5)	150	150	144	148.0
48(49)	31	27	13	23.7	6(7)	113	91	9	71.0	42(23)	297	124	96	172.3
48(28)	13	48	16	25.7	48(25)	100	60	61	73.7	48(267)	140	288	146	191.3
4(18)	11	32	41	28.0	42(5)	140	67	20	75.7	Av.	72.2	63.8	39.5	
48(43)	24	36	26	28.7	48(43)	150	44	63	75.7					
46(14)	42	9	35	28.7	1(13)	15	107	107	76.3					

from 1.4 seeds to 191.2 seeds per panicle for the 3-year average. Inclusion of such divergent materials in an analysis of variance is not a legitimate procedure. To overcome this difficulty, the 51 clones were separated into 5 classes, 1 to 10, 11 to 25, 26 to 50, 51 to 100, and 101 to 200, on the basis of average number of seeds per panicle for the two years. Each group then was analyzed separately. In the separation of variance into its components, the procedure recommended by Cochran (2) for experiments with perennial crops was followed (Table 2).

Probably the most striking fact revealed by this analysis is the extremely high mean square for error in each of the five groups. Furthermore, the magnitude of the mean square for error increased greatly with each increase in mean seed set of the group of clones. This relationship of mean square to mean was expected and was the basis for separation of the clones into groups.

The value of F for comparison of mean square for years with mean square for error (b) was greater than F for P of 0.01 in two groups and less than F for P of 0.05 in three groups. Therefore, it may be concluded that statistically significant differences between years were obtained with some clones but not with others. The differential behavior of clones in different years is indicated further by the fact that F for comparison of the interaction clones×years with error (b) exceeded P of 0.05 in two of the groups. In one of these two groups, the difference between years was not significant. Despite the differential behavior of the clones in different years, there were, nevertheless, significant correlations between the seed set of the clones in those years. The correlation coefficient of the seed set of the clones was 0.498 between 1938 and 1939 and 0.744 between 1939 and 1940. Both of these values are higher than r for P of 0.01 (Fisher, 3, Table VA).

VARIATIONS WITHIN YEARS

The factors contributing to the high error mean squares obtained in this experiment are of interest. The data were taken in 1940 in such a manner as to permit an analysis of the components of the error variance. Three bags were placed on each of two plants within each replicated clonal row, thus affording data on variation between bags on the same plant (within plants) and between plants within clonal rows. Complete data of this sort were obtained from 39 clones. For the analysis of variance, the clones again were separated into five groups on the basis of mean seed set and each group was analyzed separately (Table 3).

The relationship of the error variance to the sampling variance has been discussed by Immer (6). In this experiment, the error variance consists of two components, *viz.*, (a) the true variation between clonal rows within replications, and (b) the variance of the mean between plants within clonal rows. The mean square between plants within rows, in turn, contains the two components (a) true variance between plants, and (b) the variance of the mean among bags on the

TABLE 2.—*Analysis of variance of number seeds per panicle set under bag on 51 parental clones in 1939 and 1940, the clones being grouped on the basis of mean seed-set and each group was analyzed separately.*

Variation due to	Range of clones in average number of seeds per panicle														
	1 to 10			11 to 25			26 to 50			51 to 100			Over 100		
	D/F	Mean square	F	D/F	Mean square	F	D/F	Mean square	F	D/F	Mean square	F	D/F	Mean square	F
Replications	2	13.57	2.11	2	215	—	2	1,030	—	2	7,539	3.36	2	22,850	4.20*
Clones	8	26.10	4.06†	7	48	—	11	236	—	10	1,251	—	10	15,782	2.90*
Error (a)	16	6.42	—	14	192	—	22	1,418	—	20	2,245	—	20	5,446	—
Years	1	0.00	—	1	536	2.01	1	16,323	52.68†	1	8,951	3.18	1	47,126	16.90†
Clones×years	8	7.76	2.79*	7	402	1.51	11	762	2.46*	10	4,224	1.50	10	3,800	1.36
Rep.×years	2	18.17	6.52†	2	174	—	2	1,665	5.37*	2	4,068	1.44	2	29,426	10.55†
Error (b)	16	2.78	—	14	266	—	22	310	—	20	2,815	—	20	2,788	—

*Exceeds value of F for P of 0.05.
†Exceeds value of F for P of 0.01.

TABLE 3.—*Analysis of variance of number of seeds per panicle set in 1940 on plants of parental clones, the clones being grouped according to mean seed set and each group was analyzed separately.*

Variation due to	Range of clones in average number of seeds per panicle														
	1 to 10			11 to 25			26 to 50			51 to 100			Over 100		
	D/F	Mean square	F	D/F	Mean square	F	D/F	Mean square	F	D/F	Mean square	F	D/F	Mean square	F
Replications	2	115.50	2.60	2	44.	—	2	962	—	2	6,183	1.18	2	5,616	—
Clones	11	123.01	2.77*	8	150	—	6	1,486	1.19	5	4,737	—	4	6,808	1.12
Error	22	44.47	2.07[1]*	16	348	1.74[1]	12	1,250	2.48[1]*	10	5,236	2.70[1]*	8	6,103	3.18[1]*
Within rows of clones	36	21.45	1.63[2]*	27	200	1.12[2]	21	504	1.46[2]	18	1,941	1.60[2]	15	1,920	1.31[2]
Within plants	144	13.12	—	108	179	—	84	344	—	72	1,213	—	60	1,464	—

[1]F = Error variance/variance within rows of clones.
[2]F = Variance within rows of clones/variance within plants.
*Value of F exceeds F for P of 0.05 with appropriate D/F.

same plant. This relationship can be expressed algebraically as follows:

Let K = variance of the mean for error.
p = estimated true variance between clonal rows.
q = estimated true variance between plants within rows.
r = variance between bags on a plant.
N = number of replications.
n = number of plants in each row.
m = number of bags on each plant.

Then $K = \frac{1}{N}\left\{p + \frac{1}{n}\left[q + \frac{r}{m}\right]\right\}$ which becomes upon reduction

$$m = \frac{r}{nNK - np - q}.$$

By substituting into this formula the values obtained from Table 3 it is possible to estimate the numbers of replications, plants per replicated row, and bags per plant necessary to obtain any desired error variance K. The results of such calculations are presented in Table 4. In the calculations of total numbers of bags, since fractions of bags obviously can not be used, one was used if the number of bags per plant was less than one or only slightly more than one. With three replications and only one plant per replicated row, sufficient bags per plant could not be used to give an error mean square as low as that which was obtained in this experiment by using three replications, two plants per replicated row, and three bags per plant. On the other hand, had three plants per clonal row been bagged, a single bag per plant would have been sufficient to have given the same error variance. This would have involved use of only nine bags instead of the 18 actually used. To obtain an error variance equal to one-half that obtained in this experiment, a minimum of six replications would be necessary.

It is possible also to estimate, by use of the formula given above, the maximum precision obtainable with any particular experimental set-up. In the experiments described in this paper, there were three replications and five plants in each replicated row. Assuming that six bags can be placed on each plant, the error variance of the mean of the 0 to 10 group could be reduced only to 12.53 as compared with 14.82 obtained by use of three bags on two plants in each replication. It is apparent from these results that much increase in precision can be obtained only by increasing the number of replications.

FACTORS AFFECTING VARIATION

The effects of the use of cotton for protection of the culms, the number of panicles per bag, and the order of maturity of panicles on the plant upon number of seeds per panicle set under bag are shown in Table 5 and the analysis of variance of these data is presented in Table 6. It is apparent that the use of cotton around culms at the base of the bag was without effect upon seed set, the mean

TABLE 4.—*The numbers of replications, plants per replicated row, and bags per plant required to give the same mean error variance as obtained in this experiment and the numbers required to reduce the mean error variance to one-half.*

Range of clones in average number of seeds per panicle																			
0–10				11–25				26–50				51–100				Over 100			
No. of rep.	No. of plants	No. of bags	Total	No. of rep.	No. of plants	No. of bags	Total	No. of rep.	No. of plants	No. of bags	Total	No. of rep.	No. of plants	No. of bags	Total	No. of rep.	No. of plants	No. of bags	Total
To Obtain Same Mean Error Variance as in This Experiment																			
3	1	—	—	3	1	—	—	3	1	—	—	3	1	—	—	3	1	—	—
3	2	3.0	18	3	2	3.0	18	3	2	3.0	18	3	2	3.0	18	3	2	3.0	18
3	3	0.87	9	3	3	1.12	9	3	3	0.94	9	3	3	0.88	9	3	3	1.01	9
4	1	1.55	8	3	4	0.69	12	4	1	1.23	8	4	1	1.03	4	4	1	0.94	4
4	2	0.38	8	4	1	0.83	4	4	2	0.36	8	4	2	0.31	8	—	—	—	—
To Obtain a Mean Error Variance Equal to One-half of Error Variance in This Experiment																			
6	2	3.0	36	6	2	3.0	36	6	2	3.0	36	6	2	3.0	36	6	2	3.0	36
6	3	0.87	18	6	3	1.12	18	6	3	0.94	18	6	3	0.88	18	6	3	1.01	18
7	1	12.36	84	7	1	10.21	70	7	1	4.85	35	7	1	3.96	28	7	1	2.64	21
7	2	0.68	14	7	2	1.02	14	7	2	0.65	14	7	2	0.56	14	7	2	0.58	14

TABLE 5.—*Effects of protection of the culms with cotton, number of panicles per bag, and order of maturity of panicles upon the average number of seeds per panicle set under bag.*

No. panicles per bag	Cotton		No cotton		Average
	Early	Late	Early	Late	
1	78.17	41.75	73.33	47.33	60.15
2	78.00	44.08	89.17	40.92	63.04
4	66.42	41.00	72.00	38.67	54.52
8	50.42	31.17	48.42	28.58	39.65
Average	68.25	39.50	70.73	38.88	54.34
Average	53.88		54.80		

number of seeds per panicle being nearly the same in these two treatments. The mean square for order of maturity was significantly larger than mean square for error (c). The average seed set of the early panicles was almost twice that of the late panicles (Table 5), indicating that this could be an important factor contributing to nonheritable variability in seed set under bag. The four clones differed 6 days in date of maturity and the mean square for interaction of clones×maturity, although statistically significant, was much smaller

TABLE 6.—*Analysis of variance of data summarized in Table 5.*

Variation due to	D/F	Sums of squares	Mean square	F
Replications	2	11,158	5,579	1.75
Clones	3	31,044	10,348	3.24
Error (a)	6	19,160	3,193	
Cotton	1	41	41	—
Clones×cotton	3	2,644	882	—
Error (b)	8	17,946	2,243	—
Maturity	1	44,074	44,074	49.92†
Clones×maturity	3	8,518	2,839	3.22*
Cotton×maturity	1	110	110	—
Clones×cotton×maturity	3	6,047	2,016	2.28
Error (c)	16	14,127	883	—
Panicles	3	15,618	5,206	5.84†
Clones×panicles	9	6,778	753	—
Cotton×panicles	3	247	82	—
Maturity×panicles	3	2,804	935	—
Clones×cotton×panicles	9	14,567	1,619	1.82
Clones×maturity×panicles	9	6,081	676	—
Cotton×maturity×panicles	3	1,020	340	—
Clones×cotton×maturity×panicles	9	4,584	509	—
Error (d)	96	85,568	891	—
Total	191	292,141		

*F for P of 0.05 = 3.24.
†Exceeds value of F for P of 0.01.

than mean square for clones. Therefore, it seems probable that the lower seed set of the late panicles may be attributed to their inherently poorer ability to set seed rather than to unfavorable environmental conditions at the time of flowering and seed setting. The reduced seed-setting ability of the late panicles probably was caused to a considerable extent by the smaller number of florets as indicated by the smaller size of these panicles. Whether other factors also were involved was not determined. Comparison of the mean square for number of panicles per bag with mean square for error (d) gave a value of F in excess of that for P of 0.01. It is apparent from Table 5 that the results from one and two panicles per bag were not significantly different. Comparison of the seed set of two panicles per bag with four panicles per bag gave D/S.E. of 1.398 which is not statistically significant, while comparison of four with eight gave D/S.E. of 2.44. P is less than 0.05 and this difference, therefore, may probably be regarded as statistically significant.

DISCUSSION

Several investigators, including Walle (see Stapledon, 13), Schultz (11), and Smith[5] have reported interannual variations in self-fertility of plants of orchard grass and have suggested that plants reacted in a differential manner in the different years. In the absence of statistical analysis, it is impossible to judge the significance of these variations. In the investigations reported here, where replication permitted an estimation of error, the results confirm the suggestions of previous investigators that plants of orchard grass may react in a differential manner in different years with regard to seed set with self-pollination.

Probably the most striking feature of the results reported here is the extremely high error mean square, indicating a large amount of random variation in seed-setting under bag. In the various fertility classes, the standard error of a single determination approached the magnitude of the mean of the group. It is apparent that data based upon one or a few determinations are of little reliability, particularly for critical comparisons. Schultz (11) found that the correlation coefficient between years for selfed seed-setting was on the borderline of statistically significance, while Smith[6] reported a nonsignificant value for orchard grass. In contrast, the interannual correlation coefficients obtained in this study using replicated experiments were highly significant statistically.

The sampling study, which permitted an analysis of the components of the error variance, showed that there were random fluctuations in seed set among bags on the same plant, among adjacent plants of the same clone (within clonal rows), and among rows of clones. Variations in selfed seed set among heads on the same plant of various grass species were reported by Fruwirth (4), Clarke (1), Hayes and Garber (5), and Nilsson (10). This point has been emphasized particularly by Smith.[7] Fruwirth (4) and Jenkin (7) have stressed the lack of

[5]*Loc. cit.*
[6]*Loc. cit.*
[7]*Loc. cit.*

reliability of one or a few tests of self-fertility for evaluating a particular plant or clone, and Smith[8] reported agreement with these conclusions. The results reported here served to emphasize further the need for careful experiments designed to reduce and evaluate properly the experimental error if critical comparisons are to be made among plants of orchard grass.

The study of factors influencing seed set under bag emphasize two precautions which must be observed where critical data are required. Variations in seed set due to numbers of panicles enclosed per bag might be a serious factor, particularly if as many as eight panicles were used. Furthermore, all plants which are to be compared should be bagged at similar stages of maturity since on a particular plant the earlier panicles were found to set considerably more seed than the later ones.

SUMMARY

Inter- and intra-annual variations in seed set under bag of plants of orchard grass, *Dactylis glomerata* L., were analyzed, using 51 clones distributed at random in three replications. The differences between years and the interaction of clones×years were statistically significant.

The mean square for error was high; the standard error of a single determination approached the magnitude of the mean seed set. A sampling study revealed that the error variance was composed of variation among clonal rows within replications, among plants within clonal rows, and among bags on each plant. A formula has been given from which methods of reducing the error variance may be calculated.

In a study of factors affecting seed set under bag, protection of the culms with cotton at the base of the bag was without effect. One, two, and four panicles enclosed per bag were not statistically significantly different from each other in number of seeds per panicle, but eight panicles per bag resulted in decreased seed set. The earlier panicles set significantly more seeds than the later panicles on the same plant.

LITERATURE CITED

1. CLARKE, S. E. Self-fertilization in timothy. Sci. Agr., 7:409–439. 1927.
2. COCHRAN, W. G. Long-term agricultural experiments. Suppl. Jour. Roy. Statistical Soc., 6:104–148. 1939.
3. FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 6. 1936.
4. FRUWIRTH, C. Beiträge zu den Grundlagen der Züchtung einiger landwirtschaftlicher Kulturpflanzen. V. Gräser. Naturwissenschaftliche Zeitschr. fur Forst- und Landwirtschaft, 14:127–149. 1916.
5. HAYES, H. K., and GARBER, R. J. Breeding crop plants. New York: McGraw-Hill Book Co., Inc. Ed. 2. 1927.
6. IMMER, F. R. A study of sampling technic with sugar beets. Jour. Agr. Res., 44:633–647. 1932.
7. JENKIN, T. J. Self-fertility in perennial ryegrass. Welsh Plant Breeding Sta. Bul. Ser. H, No. 12:100–119. 1931.
8. MYERS, W. M. Heritable variations in ability to set seed under bag among plants of *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 34: 1042–1051. 1942.

[8]*Loc. cit.*

9. ———, and CHILTON, S. J. P. Correlated studies of winter-hardiness and rust reaction of parents and inbred progenies of orchard grass and timothy. Jour. Amer. Soc. Agron., 33:215–220. 1941.
10. NILSSON, FREDRIK. Studies in fertility and inbreeding in some herbage grasses. Hereditas, 19:1–162. 1933.
11. SCHULTZ, H. K. A study of methods of breeding orchard grass (*Dactylis glomerata* L.). Jour. Amer. Soc. Agron., 33:546–558. 1941.
12. SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934.
13. STAPLEDON, R. G. Self- and cross-fertility and vigor in Cocksfoot grass (*Dactylis glomerata* L.). Welsh Plant Breeding Sta. Bul. Ser. H, No. 12:161–180. 1931.

SEASONAL VARIATIONS IN DROUGHT RESISTANCE OF EXPOSED RHIZOMES OF QUACK GRASS[1]

S. T. DEXTER[2]

IN the eradication of quack grass, several damaging factors may be made to operate in varying degrees. If the grass is plowed under and disced frequently to prevent the development of foliage and photosynthesis, starvation for organic foods may finally be a major factor in the death of the rhizomes. Under such conditions, the rapidity of sprouting is an outstanding consideration (1, 3),[3] since by sprouting exhaustion of reserve foods is hastened. Rhizomes high in nitrogen have been found to sprout more rapidly than those low in nitrogen, and were, when somewhat damaged by sprouting or by exposure to drought, far more susceptible to attack by molds (1, 2).

When quack grass is worked up with a field cultivator and the loosened rhizomes are brought to the surface of the ground, a different situation arises. Here, survival may be due almost entirely to endurance of partial desiccation. The effect of a combination of partial sprouting and partial desiccation has been considered in another paper (2). In connection with previous experiments, considerable differences in simple drought resistance appeared to exist in rhizomes dug throughout the season, but no method was available to provide a reliably constant exposure to drought.

MATERIAL AND METHODS

To obtain relatively constant conditions of drought in this experiment, a double-walled incubator was fitted with a suitable thermostat, heater, fan, and calcium chloride drying pans. In this chamber, exposure of the rhizomes could be made at any time of year.

At East Lansing, Mich., samples of quack grass rhizomes were dug from an old, uniform, established sod, at intervals throughout the years 1939 and 1940. On this sod, the top growth was scanty but was never cut during this period. Additional samples were dug at the Lake City Experiment Station through the seasons of 1939, 1940, and 1941 from sods of various ages growing under various conditions.

From these sods, rhizomes were selected in such a manner that all dead rhizomes and all rhizomes newly formed during the current year were rejected. The rhizomes were so selected as to sample as adequately as possible the healthy, mature rhizomes in the sod. The rhizomes were washed free of soil, were cut into pieces 3 or 4 cm long (two or three internodes), and were dried of superficial moisture by rubbing with blotting paper. Most of the roots and leaf scales were removed in the course of the preparation of the sample.

Samples of rhizomes were weighed out for determination of dry matter, carbohydrates, total nitrogen, and drought resistance. The latter samples were

[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 594 (New Series). Received for publication June 17, 1942.

[2]Research Associate in Farm Crops.

[3]Figures in parenthesis refer to "Literature Cited", p. 1136.

spread out thinly in wire trays. These trays were placed in the drought chamber (35° C) where the fan circulated the warm air over the samples and the calcium chloride. After each prescribed period of exposure, the samples were removed, reweighed, and stored in a refrigerator between moist blotters until all samples had been exposed. All samples, together with the checks, were then placed between moist blotters in a seed germinator at 28° C. After 10 days, the samples were removed from the blotters and the new sprouts counted and weighed. Note was made of the degree of molding when samples differed markedly in this regard.

EXPERIMENTAL RESULTS

1939 DATA, EAST LANSING PLOT

From April 13 to Dec. 7, samples were dug at short intervals. Two samples of 5 grams each were exposed for 0, 3, 6, 10 and 24 hours in the drought chamber. Table 1 presents the data, giving the percentage of moisture left in the samples following various exposures to drought and weights of sprouts developed in a subsequent 10-day period in a germinator. The possibility of a high percentage of error in the value for the percentage of water left in the sample should be noted for the 24-hour exposure. Slight variations between samples would make this figure particularly unreliable. In any case, there appears to be no connection between the percentage moisture left following any given exposure and the degree of sprouting, if the whole season is considered. For example, the samples dug on Nov. 16 and June 19 are very similar in percentage moisture for various exposures, yet differ most notably in ability to sprout.

The data in Table 1 show clearly a marked seasonal variation in sprouting ability and in ability to withstand drought. That quack grass and other weeds vary in these respects throughout the year has been well recognized for many years. In this particular year, and with the field of quack grass involved, the date of apparent ease of killing is earlier than commonly stated. In 1940, the ordinary date (June 1–15) was more closely approximated. (See, also, Dexter, 1.)

THE 1940 DATA

In 1940, further samples were dug and exposed to drought. Table 2 gives the weights of sprouts formed in the subsequent period in the germinator. Samples were analyzed for carbohydrate fractions and for total nitrogen in order to gain some idea of the nature of drought resistance. Since the plots at East Lansing were given up to another department in the middle of the summer, further samples of rhizomes were dug at Lake City as indicated.

Reducing sugars, total sugars, starches and dextrins (by salivary digestion), and hemicelluloses (1.5% sulfuric acid, 2.5 hours on steam bath) were determined by the Bertrand method. Total nitrogen determinations were made by the Experiment Station Chemistry Laboratory. Table 3 shows these values. A column giving the weights of sprouts of the sample not treated in the oven for each date is included for easy comparison.

Figs. 1, 2, and 3 present these data more clearly to show seasonal trends.

TABLE 1.—*Data from the East Lansing plot, 1939.**

Date dug	Percentage content of water in the rhizomes after drying					Green weight in grams of new sprouts formed in germinator from 10 grams of treated rhizomes						
	0	3 hours	6 hours	10 hours	24 hours	0	3 hours	6 hours	10 hours	24 hours	Total	Remarks
Apr. 13	61.2	39.8	30.5	20.8	9.35	1.00	0.51	0.30	0.00	0.00	1.81	No field growth
26	59.2	38.2	26.4	12.1	2.86	1.02	0.22	0.09	0.00	0.00	1.33	
May 11	58.8	42.6	32.7	20.8	6.79	0.51	0.05	0.01	0.00	0.00	0.57	Leaf spot prevalent on grass
15	—	—	—	—	—	0.01	0.01	0.00	0.00	0.00	0.02	Poor growth in field
22	58.2	38.0	28.2	17.4	6.28	0.02	0.01	0.00	0.00	0.00	0.03	Poor growth in field
June 1	59.0	41.1	29.8	—	8.66	0.03	0.03	0.00	0.00	0.00	0.06	Poor growth in field
8	57.6	39.6	27.9	15.5	5.36	0.15	0.08	0.01	0.00	0.00	0.24	Poor growth in field
19	58.0	39.7	27.6	16.3	4.55	0.23	0.06	0.03	0.00	0.00	0.32	Poor growth in field
30	57.8	37.6	26.5	14.2	2.73	0.35	0.08	0.01	0.00	0.00	0.44	Poor growth in field
July 12	56.4	39.8	28.9	18.0	6.01	1.02	0.41	0.03	0.00	0.00	1.46	Soil very dry
24	54.8	39.4	30.7	20.7	8.51	0.57	0.06	0.04	0.00	0.00	0.67	Soil very dry
Aug. 7	58.4	42.6	31.8	21.5	9.96	0.81	0.54	0.05	0.00	0.00	1.40	Soil very dry
21	58.4	40.9	32.0	23.0	9.18	1.40	0.40	0.28	0.05	0.00	2.13	Soil moist
Sept. 5	60.0	42.0	31.5	20.3	9.51	1.10	0.50	0.12	0.04	0.00	1.76	Soil moist
14	60.0	42.2	32.4	20.6	4.77	1.55	0.32	0.28	0.01	0.00	2.16	Soil moist, hot weather
25	58.2	40.6	29.4	20.2	6.28	1.88	1.13	0.58	0.14	0.00	3.73	Soil dry
Oct. 6	55.4	38.1	27.4	18.3	5.51	1.30	0.33	0.04	0.00	0.00	1.67	Soil damp
23	59.0	41.4	30.7	18.7	7.66	0.89	0.57	0.12	0.01	0.00	1.59	Soil damp, some growth
Nov. 9	59.8	41.7	31.4	20.2	—	1.39	0.93	0.22	0.05	0.00	2.59	Soil damp, some growth
16	58.8	39.4	29.5	17.6	6.37	2.31	1.67	0.97	0.07	0.00	5.02	Soil wet
30	60.8	40.6	31.2	20.3	9.26	2.20	1.29	0.51	0.12	0.00	4.12	Soil frozen
Dec. 7	58.8	39.8	29.2	16.3	4.19	1.80	1.24	0.57	0.14	0.00	3.75	Soil thawed

*Duplicate 5-gram samples of quack grass rhizomes, dug in 1939 at East Lansing, Mich., received the indicated exposure to drought. The degree of desiccation during exposure to drought is indicated by the percentage of moisture remaining after drying for the periods indicated. The weights of sprouts formed in the subsequent period in the seed germinator are shown for each degree of desiccation on each date.

TABLE 2.—*The 1940 data.**

Date dug	Dry weight (5-gram sample), grams	Green weight of new sprouts formed in germinator for 10 grams of treated rhizomes†					Remarks
		0	3	6	10	Total	
				"Old" Rhizomes			
Apr. 9	1.93	2.15	0.86	0.19	—	3.20	No green leaves
22	1.93	1.63	1.14	0.29	—	3.06	Ground frozen, some growth
May 6	1.90	0.94	0.27	0.01	—	1.22	Longest leaves 4 in., green
13	1.98	0.68	0.00	0.00	—	0.68	Leaf sheathes, 2 in. long
21	2.09	0.56	0.02	0.00	—	0.58	
June 4	2.15	0.08	0.01	0.00	—	0.09	Noticeable new rhizomes
13	2.12	0.01	0.00	0.00	—	0.01	New rhizomes predominant; old rhizomes dying
24	2.07	0.04	0.00	0.00	—	0.04	Some new rhizomes emerged from ground
July 8	2.13	0.03	0.00	0.00	—	0.03	
				"New" Rhizomes			
June 4	0.89	0.00	0.00	0.00	0.00	—	New rhizomes, just forming, about 2 in. long
13	1.32	0.23	0.21	0.06	0.01	0.50	New rhizomes
24	1.39	0.75	0.76	0.85	0.04	2.40	New rhizomes
July 8	1.72	0.45	0.20	0.05	0.00	0.70	New rhizomes

*Duplicate 5-gram samples of quack grass rhizomes dug in 1940 at East Lansing received the indicated exposure to drought. The green weight of sprouts formed in the subsequent 10-day period in the germinator are shown.
†No sprouts in samples of old rhizomes exposed 10 and 24 hours.

Fig. 1 shows the seasonal variation in sprouting ability in the years 1939 and 1940 (Tables 1 and 2).

Fig. 2 compares the sprouting ability of the rhizomes dug at East Lansing in 1940 with their percentage content of total nitrogen as the season advanced (Tables 2 and 3).

Fig. 3, in a spot diagram, compares the percentage of total nitrogen to the total weight of sprouts in 0, 3, 6, and 12 hours exposure for all samples dug at East Lansing and Lake City in 1940 (Table 3). When the Chemistry Department labelled an analysis "poor checks", etc., the sample was not included. The "new rhizomes" dug at East Lansing are omitted.

The seasonal variation in sprouting ability is clearly shown in Fig. 1. The relationship between the nitrogen in the rhizomes and the sprouting ability is evident as the season advances (Fig. 2).

The spot diagram in Fig. 3 compares samples dug from several environments, rhizomes of various ages, and dug throughout the season, both at Lake City and at East Lansing. Even when all these complexities were added to the picture, the relationship between sprouting ability and content of total nitrogen remained clear. Only when the nitrogen was excessively high did a positive relationship between sprouting and carbohydrate content manifest itself. The data in Table 3 indicate that only a relatively slight relationship

existed between sprouting ability and carbohydrate content. When the nitrogen content was high, unusually great sprouting ability was associated with unusually high carbohydrate content. But generally speaking, in quack grass rhizomes, the carbohydrate available for use in sprouting seems more than sufficient to exhaust the supply of available nitrogen.

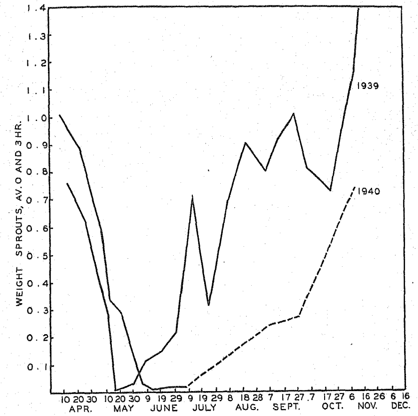


FIG. 1.—The seasonal variation in sprouting ability of mature quack grass rhizomes is shown for two seasons, 1939 and 1940. (The broken line shows data from Lake City; other figures are from E. Lansing.)

SAMPLES DUG FROM EXTREMES OF ENVIRONMENT, 1941

On three dates in 1941, samples were dug at Lake City from several locations to obtain extremes in environment. In each case, the high or low nitrogen condition of the plant was estimated by the color and vigor of growth. As before, these rhizomes were subjected to drought and subsequently sprouted. Analyses for total nitrogen and for total available carbohydrates were made. Fig. 4 shows the relationship between the weight of sprouts and the percentage of nitrogen. Samples dug from locations excessively high in nitrogen (around manure piles,

TABLE 2.—*The 1940 data.**

Date dug	Dry weight (5-gram sample), grams	Green weight of new sprouts formed in germinator for 10 grams of treated rhizomes†					Remarks
		0	3	6	10	Total	
"Old" Rhizomes							
Apr. 9	1.93	2.15	0.86	0.19	—	3.20	No green leaves
22	1.93	1.63	1.14	0.29	—	3.06	Ground frozen, some growth
May 6	1.90	0.94	0.27	0.01	—	1.22	Longest leaves 4 in., green
13	1.98	0.68	0.00	0.00	—	0.68	Leaf sheathes, 2 in. long
21	2.09	0.56	0.02	0.00	—	0.58	
June 4	2.15	0.08	0.01	0.00	—	0.09	Noticeable new rhizomes
13	2.12	0.01	0.00	0.00	—	0.01	New rhizomes predominant; old rhizomes dying
24	2.07	0.04	0.00	0.00	—	0.04	Some new rhizomes emerged from ground
July 8	2.13	0.03	0.00	0.00	—	0.03	
"New" Rhizomes							
June 4	0.89	0.00	0.00	0.00	0.00	—	New rhizomes, just forming, about 2 in. long
13	1.32	0.23	0.21	0.06	0.01	0.50	New rhizomes
24	1.39	0.75	0.76	0.85	0.04	2.40	New rhizomes
July 8	1.72	0.45	0.20	0.05	0.00	0.70	New rhizomes

*Duplicate 5-gram samples of quack grass rhizomes dug in 1940 at East Lansing received the indicated exposure to drought. The green weight of sprouts formed in the subsequent 10-day period in the germinator are shown.

†No sprouts in samples of old rhizomes exposed 10 and 24 hours.

Fig. 1 shows the seasonal variation in sprouting ability in the years 1939 and 1940 (Tables 1 and 2).

Fig. 2 compares the sprouting ability of the rhizomes dug at East Lansing in 1940 with their percentage content of total nitrogen as the season advanced (Tables 2 and 3).

Fig. 3, in a spot diagram, compares the percentage of total nitrogen to the total weight of sprouts in 0, 3, 6, and 12 hours exposure for all samples dug at East Lansing and Lake City in 1940 (Table 3). When the Chemistry Department labelled an analysis "poor checks", etc., the sample was not included. The "new rhizomes" dug at East Lansing are omitted.

The seasonal variation in sprouting ability is clearly shown in Fig. 1. The relationship between the nitrogen in the rhizomes and the sprouting ability is evident as the season advances (Fig. 2).

The spot diagram in Fig. 3 compares samples dug from several environments, rhizomes of various ages, and dug throughout the season, both at Lake City and at East Lansing. Even when all these complexities were added to the picture, the relationship between sprouting ability and content of total nitrogen remained clear. Only when the nitrogen was excessively high did a positive relationship between sprouting and carbohydrate content manifest itself. The data in Table 3 indicate that only a relatively slight relationship

existed between sprouting ability and carbohydrate content. When the nitrogen content was high, unusually great sprouting ability was associated with unusually high carbohydrate content. But generally speaking, in quack grass rhizomes, the carbohydrate available for use in sprouting seems more than sufficient to exhaust the supply of available nitrogen.

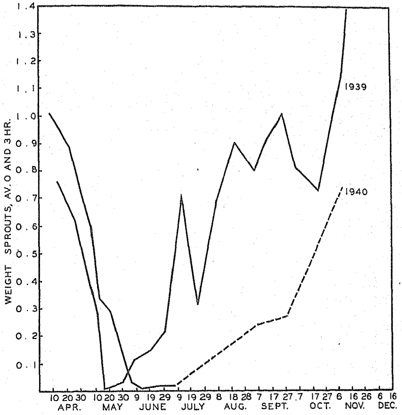


FIG. 1.—The seasonal variation in sprouting ability of mature quack grass rhizomes is shown for two seasons, 1939 and 1940. (The broken line shows data from Lake City; other figures are from E. Lansing.)

SAMPLES DUG FROM EXTREMES OF ENVIRONMENT, 1941

On three dates in 1941, samples were dug at Lake City from several locations to obtain extremes in environment. In each case, the high or low nitrogen condition of the plant was estimated by the color and vigor of growth. As before, these rhizomes were subjected to drought and subsequently sprouted. Analyses for total nitrogen and for total available carbohydrates were made. Fig. 4 shows the relationship between the weight of sprouts and the percentage of nitrogen. Samples dug from locations excessively high in nitrogen (around manure piles,

TABLE 3.—*The percentage content in the dry matter of various carbohydrate fractions and of total nitrogen of rhizomes dug on the dates and at the location indicated.**

Sample No.	Date dug, (1940), location, and age	Reducing sugar, %	Nonreducing as sucrose, %	Starch and dextrins, %	Hemicellulose as reducing sugar, %	Total available carbohydrate†	Total N, %	Weight of sprouts of check, grams‡	Total weight of sprouts, grams§
1	June 13, EL, new	2.18	7.99	13.06	11.06	23.23	1.09	0.23	0.50
2	June 24, EL, new	1.17	3.51	4.98	13.14	9.66	0.861	0.75	2.40
3	July 8, EL, new	0.80	2.31	6.27	10.43	9.38	0.546	0.45	0.70
4	Apr. 9, EL, old	1.49	4.59	5.12	15.28	11.20	0.824	2.15	3.20
5	Apr. 22, EL, old	2.44	3.91	5.58	14.02	11.93	0.761	1.63	3.06
6	May 6, EL, old	2.47	3.84	4.41	14.03	10.72	0.592	0.94	1.22
7	May 13, EL, old	1.72	2.94	4.59	13.17	9.25	0.507	0.68	0.68
8	May 21, EL, old	0.86	1.42	6.94	14.40	9.22	0.456	0.56	0.58
9	June 4, EL, old	0.63	1.16	5.04	13.96	6.83	0.334	0.08	0.09
10	June 13, EL, old	1.22	1.93	6.16	13.04	9.31	0.308	0.01	0.01
11	June 24, EL, old	1.23	1.55	5.91	17.65	8.69	0.380	0.04	0.04
12	July 8, EL, old	1.25	1.98	5.57	14.41	8.80	0.387	0.03	0.03
13	Sept. 7, LC, 1 yr.	0.45	1.47	10.26	20.34	12.18	0.690	1.36	1.81
14	Sept. 7, LC, 2 yr.	0.71	2.67	2.50	13.35	5.88	0.444	0.53	0.80
15	Sept. 7, LC, 3 yr.	1.13	1.85	8.16	15.04	11.14	0.350	0.12	0.12
16	Sept. 7, LC, 4 yr.	1.82	2.10	2.78	13.93	6.70	0.445	0.43	0.47
17	Oct. 3, LC, new	1.11	3.58	4.63	12.98	9.32	0.822‖	0.71	1.17

18	Oct. 3, LC, 1 yr.	0.77	2.30	3.32	12.97	6.39	0.687	1.17	1.83
19	Oct. 3, LC, 2 yr.	1.04	3.25	4.78	12.95	9.07	0.544	0.56	0.80
20	Oct. 3, LC, 3 yr.	2.52	2.44	4.84	19.61	9.80	0.538	0.66	0.68
21	Oct. 3, LC, 4 yr.	2.59	2.83	3.00	14.31	8.42	0.377	0.20	0.22
22	Oct. 3, LC, old	5.74	4.74	5.73	18.04	16.21	0.511	0.64	0.89
23	Nov. 11, LC, 1 yr.	0.45	3.92	18.40	16.01	22.77	0.744	2.44	6.25
24	Nov. 11, LC, 2 yr.	0.40	2.33	8.30	16.36	11.03	0.630	0.82	1.68
25	Nov. 11, LC, 3 yr.	0.70	3.64	5.91	13.73	10.25	0.460	0.57	0.80
26	Nov. 11, LC, 4 yr.	1.07	4.64	7.83	11.34	13.54	0.726	1.25	2.75
27	Nov. 11, LC, old	1.28	3.94	7.59	13.88	13.81	0.766	2.03	3.65
28	Aug. 21, LC, new	—	—	—	—	—	2.12‖	1.79	3.14
29	Aug. 21, LC, 1 yr.	—	—	—	—	—	0.994	2.21	3.87
30	Aug. 21, LC, 2 yr.	—	—	—	—	—	0.437	0.32	0.32
31	Aug. 21, LC, 3 yr.	—	—	—	—	—	0.266	0.005	0.005
32	Aug. 21, LC, 4 yr.	—	—	—	—	—	1.11	2.15	4.03
33	Aug. 21, LC, old	—	—	—	—	—	0.697	1.31	1.35
34	Sept. 7, LC, old	—	—	—	—	—	0.926	1.09	1.44
35	Sept. 7, LC, old	—	—	—	—	—	0.451	0.34	0.39

*Those dug at East Lansing (EL) were from an old sod; those dug at Lake City (LC) were from fields seeded over a period of years, thus giving rhizomes of the approximate age indicated. Thus, rhizomes 1 year old are from a field sowed to oats in 1940; those 2 years old are from a field sowed to oats (and *alfalfa*) in 1939, etc.

†Available carbohydrates considered the sum of the sugars, starch, and dextrins.

‡The weight of sprouts from the sample *not treated* in the oven.

§The summation of the weights of sprouts after 0, 3, 6, 10, and 24 hours in the oven.

‖Chemist reports analysis doubtful.

etc.) invariably failed to sprout as heavily as might have been expected. These samples, Nos. 2, 8, 9, 13, 14, and 20, are ringed in

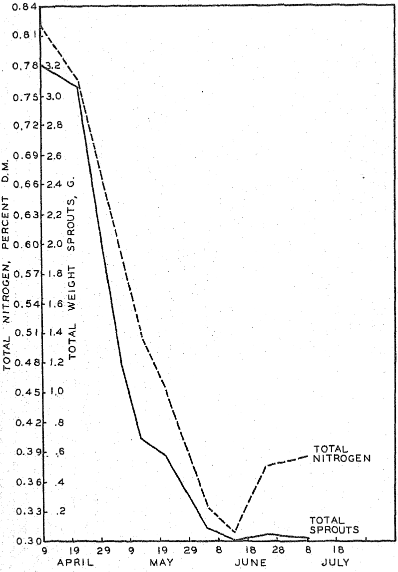


FIG. 2.—The curves show the relationship between sprouting ability and nitrogen content of rhizomes dug on the sequence of dates shown in 1940.

Fig. 4. These samples were regularly somewhat low in available carbohydrates.

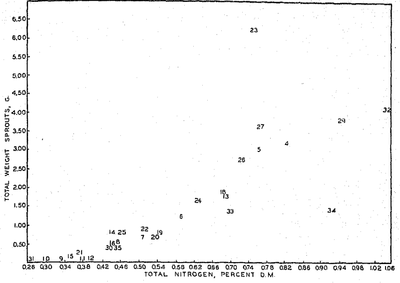


FIG. 3.—The spot diagram shows the relationship between nitrogen content and sprouting ability of rhizomes dug throughout the year from a large variety of ordinary natural locations. Sample numbers from Table 3 are used throughout.

RHIZOME FORMATION IN AN OLD SOD

During the two years in which rhizomes were dug from the old, established sod at East Lansing, interesting observations were made concerning the formation of new rhizomes in an old sod. Rhizome formation in a dense quack grass sod is usually very scanty (1). During the entire season of 1939 this was the case. In the late fall of 1939 and in the early spring of 1940, however, new rhizomes began to develop, until by July 8 a mat of new rhizomes interspersed the old sod. This growth was so noticeable that samples of "new" rhizomes were collected and subjected to desiccation and analysis for carbohydrates and total nitrogen. Very young "new" rhizomes made no growth between blotters. When a few weeks older, they were much superior in sprouting ability and in drought resistance to healthy mature rhizomes from the same sod. This would suggest that eradication should be started before these young rhizomes mature sufficiently to be vigorous. In a mixed sample, the younger rhizomes alone may survive desiccation (2). Furthermore, although there were virtually no rhizomes 1 year old in this sod in the spring and early summer of 1939 and 1940, in 1941 this sod would have been composed largely of such rhizomes. From what evidence we have, it seems likely that this sod would have been harder to kill in 1941 than in 1940.

RHIZOME FORMATION UNDER HIGH NITROGEN CONDITIONS

The great sprouting ability and susceptibility to rotting associated with a large content of stored nitrogen has been discussed previously.

From a natural culture growing in a compost pile, the long "new" rhizomes were collected and tested at intervals through the fall of 1939. Invariably these showed enormous sprouting ability and molded heavily. In the spring of 1940, further samples were sought, but these high nitrogen rhizomes were largely decayed before May 15 so that healthy samples were unobtainable. A new crop of rhizomes was developing to replace them. Heavy fertilization with nitrogen has been shown to cause the sprouting, death, and decay of old rhizomes (1), but the annual decay and replacement here observed seems worthy of record. Assuredly, the life cycle of quack grass is greatly affected by soil fertility.

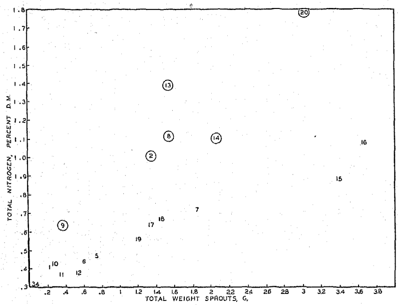


FIG. 4.—The spot diagram (of laboratory numbers) shows the relationship between sprouting ability and nitrogen content of rhizomes from low and from extremely high nitrogen conditions. The numbers within rings indicate samples dug from compost piles, around manure piles, etc. Note that they are lower in sprouting ability than would be expected, considering their nitrogen content, from comparison with ordinary samples in Fig. 3.

DISCUSSION

Quack grass rhizomes high in nitrogen sprout readily and are attacked freely by molds when slightly injured by drought or by exhaustion of organic reserves (1, 3). Rhizomes low in nitrogen are low in sprouting ability and slow to mold. Thus, while not shown to be superior in drought resistance, rhizomes low in nitrogen were found to survive sprouting or clipping or the combination of sprouting and slight desiccation better than did rhizomes high in nitrogen (2, 3).

In the eradication of quack grass, however, upon the first exposure to the sun and air, desiccation of the rhizomes continues in a good

many cases to such an extent that rain will not revive them. When quack grass rhizomes in the ordinary low nitrogen condition of June or early July are dug up thoroughly with a field cultivator from a dry soil and their roots detached from the sub-soil moisture, a relatively few hours of exposure to the air is sufficient to cause complete death, while those covered with 1 or 2 inches of dry soil may die of drought in a few days. In the case of eradication in midsummer with a field cultivator, death is caused in the great majority of cases by drought, with exhaustion of organic reserves playing a minor rôle. Careful examination of such a field often shows that sprouting of rhizomes following dislodgement is exceptional and that death occurred before there was opportunity for any material exhaustion of reserves. Examination of such fields has led to the conclusion that in most cases rhizomes surviving a season of summer fallow are those that were not subjected to the injury of partial or complete desiccation.

Samples of rhizomes slightly and repeatedly desiccated over sulfuric acid, with alternate opportunity to regain moisture from wet blotting paper, have in no case been equal in drought resistance or sprouting ability to the check samples. Detached and partially desiccated sods, simulating field conditions, have shown no subsequent increased drought resistance. In some cases, limited watering of such detached sods has been sufficient to maintain most of the original sprouting ability and drought resistance, but, in general, limited watering is likely to be injurious, since a good many of the rhizomes die outright.

In general, the attempt to eradicate quack grass is started too late in the summer. June 15 is a better date to start than August 15. In the first place, on the early date, the rhizomes are far more subject to drought injury; and in the second place, more opportunity is afforded for such drying to occur. Obviously, in most regions, this recommended time is at about the busiest season of the year. To offset this labor problem in part is the fact that the ground may be less dried out and easier to work up on the earlier date than on the latter. In field trials started at bi-weekly intervals from July 1 until November, the earlier working has always given greatly superior eradication, and in some cases, a reasonably thorough kill was effected within a period of 10 days after cultivation started.

SUMMARY

Quack grass rhizomes were dug at intervals throughout three growing seasons and were subjected to various degrees of desiccation in a "drought machine". Subsequent recovery between moist blotters in a seed germinator was used as a measure of survival. A very marked seasonal fluctuation in drought resistance and sprouting ability was found. Carbohydrate and total nitrogen determinations were made. There was found to be a close positive correlation between total nitrogen content and sprouting ability before and after exposure to drought. Rhizomes dried until the content of water remaining is 40% of the total weight may be killed in July, but only slightly injured in November. In the very early spring or late fall, rhizomes dried to a

content of 30% water may survive to a considerable extent, and in November and December, rhizomes dried to less than 20% water sometimes survived. When killing is to be accomplished largely through drying out, as in the case of the use of the field cultivator, it is suggested that the field be harrowed *very thoroughly* in the early part of the season.

LITERATURE CITED

1. DEXTER, S. T. Response of quack grass to defoliation and fertilization. Plant Phys., 11:843–851. 1936.
2. ———. The drought resistance of quack grass under various degrees of fertilization with nitrogen. Jour. Amer. Soc. Agron., 29:568–576. 1937.
3. JOHNSON, A. A., and DEXTER, S. T. The response of quack grass to variations in height of cutting and rate of application of nitrogen. Jour. Amer. Soc. Agron., 31:67–76. 1939.

NOTES

ACID SCARIFICATION OF THE SEED OF TWO CUBAN FIBER PLANTS

URENA LOBATA L. of the mallow family, widely used for fiber in the Tropics, and the related *Triumfetta semitriloba* Jacq. of the linden family are being planted in Cuba for the production of their jute-like bast fibers. In Cuba both of these as well as several other plants are called "malva." Observations indicated that the germination of seeds of these two plants under field conditions was irregular, and it appeared desirable to test the value of sulfuric acid treatments in the scarification of the seed to hasten germination.

The seed of both species is born in bur-fruits. In *Urena* the dehiscence of the five-carpeled fruit is septicidal, and each individual seed is completely enclosed in its portion of the capsular covering, part of which is copiously prickly. In *Triumfetta* the fruits rarely dehisce, but when they do the dehiscence of the two- to five-cavity fruits is loculicidal, and the seed is entirely freed of the copiously prickly capsular covering. However, natural dehiscence is so rare that, for practical purposes, the "seed" of *T. semitriloba* is in reality the two- to five-seeded fruit. Since these bur-fruits mass together forming clusters, good seed distribution at planting time is difficult, if not impossible. Acid scarification, therefore, has two objectives, first, to assure a good distribution of the seed at planting time by eliminating the bristles with which the capsules are beset, and second, to make germination prompt and even.

Because of the impractical, tedious difficulty in hulling the seeds of *T. semitriloba* no hulled seeds of this species were included in the experiment. Two hundred seeds collected at random from wild plants

TABLE 1.—*Effects of treating unhulled and hulled seeds of Urena lobata and unhulled seeds of Triumfetta semitriloba with 96.5% sulfuric acid for various periods of time.*

Treatment-time in acid, min.	*Urena lobata*				*Triumfetta semitriloba*, unhulled seeds, %	
	Hulled seeds, %		Unhulled seeds, %			
	Scarified	Germinated	Scarified	Germinated	Scarified	Germinated
5	100.0	62.5	96.5	33.0	100.0	2.5
10	100.0	75.0	96.5	35.0	99.5	11.5
15	100.0	75.0	97.5	38.5	100.0	22.5
30	99.5	82.0	95.5	58.5	99.5	15.5
60	99.5	87.0	99.5	76.5	99.5	22.0
90	99.5	78.5	98.5	43.5	100.0	14.5
120	100.0	47.0	99.5	84.0	100.0	21.5
180	100.0	60.5	100.0	92.0	100.0	20.5
240	100.0	43.0	100.0	57.0	100.0	11.5
300	100.0	23.0	100.0	32.5	97.5	20.5
360	100.0	4.5	100.0	35.0	100.0	17.0
None*	41.5	22.0	44.0	0	0	0

*Controls soaked in water only for 48 hours.

in western Cuba during December 1941 were used in each treatment. The seeds were quickly covered with 96.5% sulfuric acid and allowed to remain immersed for periods of from 5 minutes to 6 hours. The seeds were then drained and rapidly flushed with running water to free them of acid. A seed was considered scarified when it was swollen after subsequent soaking in water for 48 hours. The swollen seeds were transferred to moist blotters to determine the viability by germination. Table 1 shows the effects of the various treatments compared with controls soaked in water for 48 hours.

From this experiment the following results were evident:

1. Scarification was practically complete in all cases at the end of the 5-minute acid treatment, although germination was improved by longer treatments.
2. The approximate optimum acid treatment for germination for *Urena lobata* hulled seed was 1 hour, for unhulled seed 3 hours, and for unhulled *Triumfetta semitriloba* 15 minutes.
3. In the case of *U. lobata* germination dropped off following the optimum treatment; however, with *T. semitriloba* germination was not adversely affected through the range of longer treatments.
4. Water-treated seeds germinated much more poorly than the acid-treated seeds, or not at all.
5. The objectionable bristles or spines of the bur-fruits were practically removed after 15 minutes in the acid, thus eliminating the clustering of seeds or fruits, as shown in Fig. 1. Such seeds could be readily planted with a grain drill for large-scale plantings.

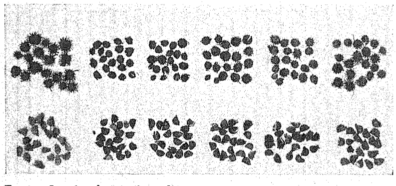


FIG. 1.—Samples of seeds of two fiber plants variously treated with sulfuric acid to remove spines and improve germination. Seeds in row at top are of *Urena lobata*; those below are of *Triumfetta semitriloba*. The seeds in the first square at left were soaked in acid for 5 minutes, the remainder successively for 10, 15, 30, and 60 minutes, respectively, and those at the right were soaked only in water for 48 hours as controls. Note abundance of spines on controls and their practical removal by the 15-minute acid treatment shown in third group from left. X¾.

6. In the case of acid-treated *T. semitriloba* fruits, the individual seeds were easily removable by slight manipulations.—CLAUD L. HORN AND JOSE E. NATAL COLON, *Puerto Rico Experiment Station, Mayaguez, P. R.*

A DEVICE FOR SAMPLING BALED HAY

FOR several years we have cut all of the hay fed to cows on feeding experiments in which hay had to be sampled and analyzed. The cut hay was then sampled by quartering. The cutting of hay even for two cows is time-consuming and expensive. In our experience a good quality of whole hay is eaten more readily than cut hay.

For the past year, the hay has been sampled in the bale by means of the Pozzo soil tube designed by F. J. Veihmeyer and described in SOIL SCIENCE (Vol. 22, pages 147–152, 1929), and manufactured by the Pozzo Machine Works of San Jose, California. Detailed drawings appear in the original article and need not be given here. This method of sampling has been highly satisfactory.

The soil sampling tube is driven lengthwise through the bale by means of a hammer and takes a perfect aliquot. The plant stems are cut into lengths not exceeding an inch. The samples from individual bales are composited. Only bales of the same cross-sectional dimensions should be used in forming a composite. Bales which are tightly pressed are easily sampled. Loose bales spring under the blows of the hammer when the sampling tube is driven. After the tube has been driven through one third of the bale the rebound is less pronounced. Arrangement of levers which compress the bale lengthwise will reduce the tendency of the bale to rebound. It is unnecessary to use a jack to remove the sampling tube from the bale.—AVERY D. PRATT, *Department of Dairy Husbandry, Virginia Agr. Exp. Station, Blacksburg, Va.*

FELLOWS ELECT FOR 1942

HOWARD CHRISTIAN RATHER

THE first Fellow to be presented to the Society is an especially handy man about his home town. As an after-dinner speaker and as a ring master for Farm and Home Week and all student programs this man is a past master. He is a popular teacher and is greatly interested in all farm crop research and has published numerous articles on pasture management, hay curing, and crop varieties. Recently he has published a new textbook on "Farm Crops".

This man served as Secretary-Treasurer of the International Crop Improvement Association in 1926 and as President in 1928. He was born in Bay Port, Michigan, September 17, 1895, and graduated from Michigan State College in 1917.

He was Agronomy Extension Specialist of Michigan State College from 1920 to 1928 and was made Professor of Farm Crops and Head of the Department of Agronomy in 1929. He attended the International Grasslands Congress in England in 1937. HOWARD CHRISTIAN RATHER, East Lansing, Michigan.

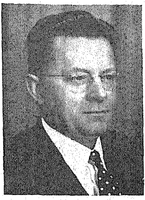
HILMER HENRY LAUDE

THE second man is an outstanding teacher, investigator, and counselor. He has published many articles in scientific journals and has written many experiment station bulletins. We find that he is interested in all phases of crop production and improvement and in the broader fields of crop ecology, especially those phases related to climate. Born in Rose, Kansas, July 9, 1887, he received his Bachelor's degree at Kansas State College in 1911, his Master's degree at Texas A. & M. College in 1918, and his Ph.D. degree in plant physiology from the University of Chicago in 1936.

This candidate started his agronomic career as Assistant Agronomist at Kansas State College in 1911–13. He was County Agricultural Agent in Missouri 1913–14; Superintendent of the Experiment Substation, Beaumont, Texas, 1914–19; Professor of Agronomy, Kansas State College, and Agronomist, Kansas Agricultural Experiment Station from 1920 to the present.

He has been an active member of the Society for many years and has served on numerous committees. HILMER HENRY LAUDE, Manhattan, Kansas.

GEORGE DEWEY SCARSETH



THE next man might have been a comedian, but instead he chose to be a soil scientist. For so young a man he has had a very diversified scientific experience. He was born at Galesville, Wisconsin, October 7, 1898, and received his college education at the University of Wisconsin, obtaining his B.Sc. degree in 1924. From 1925 to 1926 he attended Yale University and received his Ph.D. degree from Ohio State University in 1935.

He was in the Wisconsin Soil Survey from 1923–24; assistant soil chemist at the Connecticut Experiment Station, 1924–26; Soil Chemist, United Fruit Company, Honduras, 1926–28; Assistant Professor, Soil Chemistry, Alabama Polytechnic Institute, 1928–38; and Associate Professor and Professor of Soil Science at Purdue University since 1938.

He is an active member of the American Society of Agronomy and the Soil Science Society (President in 1936) and carries membership in the International Society of Soil Science. He has published numerous scientific articles in many phases of his chosen field. GEORGE DEWEY SCARSETH, Lafayette, Indiana.

KARL SPANGLER QUISENBERRY

THIS Fellow was born in Dennison, Texas, August 2, 1897, and received his B.Sc. degree from Kansas State College in 1921, his M.Sc. from Minnesota in 1925, and his Ph.D. from Minnesota in 1930. He was Instructor and Assistant Agronomist at the West Virginia Agricultural College from 1921–25; Associate Agronomist, Agronomist, and Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. He also holds the rank of Professor of Agronomy in the University of Nebraska.

This man is a member of the American Association for the Advancement of Science, of the American Society of Agronomy, and of the Genetics Association. He is in charge of cooperative hard red winter wheat improvement investigations for the U. S. Dept. of Agriculture and in charge of all small grain breeding at the Nebraska Agricultural Experiment Station. His research contributions approach close to the one-half hundred mark.

This Fellow has been active in the affairs of the Society and is chairman of the crops program for this session, and you will agree with me that he has done a fine job. His hobby is biometry. KARL SPANGLER QUISENBERRY, Lincoln, Nebraska.

CHARLES EDWIN KELLOGG

THE next Fellow is sometimes classed as an individualist. Even if this candidate is still regarded as a young man, he has made an international reputation as a soil survey and land classification scientist. He has specialized in making soil survey more useful and has increased the economic aspects of this valuable field. In addition to publishing numerous articles and bulletins he has found time to travel extensively in foreign countries.

Born in Ionia, Michigan, August 2, 1902, he received his B.Sc. degree from Michigan State College in 1925; was a Fellow at Michigan in 1926–28, and received his Ph.D. degree in 1929. He was soil scientist in the Wisconsin Geology and Natural History Survey in 1928 and 1930; Assistant Professor and Professor of Soils at North Dakota State College in 1930–1935. In this brief time he made a record as a teacher and turned out some most excellent soil students.

He belongs to many scientific societies and at present is Head Soil Scientist, Bureau of Plant Industry, U. S. Dept. of Agriculture. CHARLES EDWIN KELLOGG, Washington, D. C.

JAMES KENNETH WILSON

THE last candidate was born in Maryville, Missouri, August 5, 1881. A B.Sc. degree was received from the Oklahoma A. & M. College in 1906 and a Ph.D. degree from Cornell University in 1915. His chief diversion is tennis; at the age of 62 he won the faculty tournament at Cornell this past season. Over the years he has done this three-fourths of the time.

He was Assistant Bacteriologist at the New York State Experiment Station at Geneva from 1906–12; Assistant Plant Physiologist at Cornell University, 1912–14; Assistant Professor in Soil Technology, 1914–20; and has held the chair of Professor of Soil Bacteriology at Cornell University from 1920 to the present. In 1930 he won the Chilean Nitrate of Soda Award.

This Fellow has published numerous articles on legume bacteria, ammonia-oxidizing bacteria, azotobacter, and many other subjects. He belongs to many scientific societies and is an outstanding teacher in his field. This man represents a splendid type of an American gentleman. JAMES KENNETH WILSON, Ithaca, New York.

MINUTES OF THE THIRTY-FIFTH ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

THE THIRTY-FIFTH ANNUAL MEETING of the Society was held in the Hotel Statler in St. Louis, Missouri, November 11, 12, and 13. There were 393 members and guests registered. The meetings were held jointly with the Soil Science Society of America.

The general meeting of the Society was held Thursday morning, November 12, with President Richard Bradfield presiding. Dr. O. S. Aamodt, Bureau of Plant Industry, presented a paper on "The Seed Situation and the War". This was followed by a paper by Dr. F. W. Parker, Bureau of Plant Industry, on "Fertilizers in the War Program". Both papers were well received and will be published in an early number of the JOURNAL. Following these papers a committee composed of Dean M. F. Miller of Missouri, Dr. L. F. Graber of Wisconsin, and Dr. R. D. Lewis of Ohio led a round table discussion on "The American Society of Agronomy and the War". This discussion brought forth a number of suggestions of ways in which agronomists and the Society can contribute to the war effort. The report of the committee as approved by the Society appears on pages 1150 to 1152.

The annual dinner of the Society was held on Thursday evening at which time President Richard Bradfield delivered the presidential address on the subject "Our Job Ahead" (pages 1065 to 1075).

The Crops Section had one general program and 11 subsectional meetings. Thirty-four papers were presented and conferences held on statistics, teaching, alfalfa, and corn improvement.

The Soil Science Society of America had one general program and 13 sectional programs. A total of 82 papers was presented. In addition to formal papers there were discussions of soil survey technics, problems of soil classification, and the contribution of soil survey to the war effort and post-war planning.

The annual banquet of the Soil Science Society was held on Wednesday evening, at which time D. Howard Doane, of the Doane Agricultural Service, St. Louis, Missouri, gave an address on "Soil Science and its Practical Application".

One joint meeting of interest to both crops and soils members was held on Friday morning. At this session five papers were presented on the general topic of cropping practices in the Great Plains.

The Auditing Committee appointed by President Bradfield consisted of Dr. B. A. Brown and Dr. T. L. Martin. The Nominating Committee consisted of President Bradfield, *Chairman*, Emil Truog, H. K. Hayes, R. M. Salter, and R. I. Throckmorton.

FELLOWS ELECT

Vice President F. D. Keim announced the Fellows Elect and presented certificates at the annual dinner on the evening of November 12. The following were elected Fellows of the Society: Charles E. Kellogg, H. H. Laude, K. S. Quisenberry, H. C. Rather, G. D. Scarseth, and J. K. Wilson.

NOMINATING COMMITTEE

The nominating committee presented the name of Frank W. Parker for Vice President of the Society. Upon motion from the floor the Secretary was instructed to cast the ballot for the nominee and he was declared unanimously elected.

Respectfully submitted,
G. G. POHLMAN, *Secretary.*

REPORTS OF OFFICERS AND COMMITTEES

REPORT OF THE EDITOR

TO ALL outward appearances, the war has had little effect on the JOURNAL. Almost exactly the same number of papers, notes, and book reviews have passed over our desk this year as in 1941. The 1942 volume of the JOURNAL will contain 119 papers, 31 notes, and 18 book reviews, and will comprise close to 1,200 pages.

We had 16 papers on hand approved for publication as of November 1st, while 25 papers were in the hands of reviewers or had been returned to the authors for revision. Nine contributions were refused publication for one reason or another.

The advertising income has held up remarkably well throughout the year, absorbing most, if not all, of the overhead of the Editor's office. Thus, it has been possible to publish a volume that will run a few pages larger than the 1941 volume.

But the picture is changing and it is difficult to predict at this time just what we may expect in 1943. The Secretary's report will show a considerable loss in subscriptions, especially foreign subscriptions, and some shrinkage in memberships as well as more and more agronomists join the armed forces. In addition, we shall probably experience some loss in advertising as industrial plants are converted to war production. All of this will mean a reduced income for 1943, which in turn will mean curtailed publication to keep within our resources.

We do not anticipate any material increase in printing costs, although there will be some. We do foresee, however, a decline in quality, particularly with respect to paper stocks. Paper manufacturers have been faced for sometime with a greatly reduced allotment of bleaching agents with the result that each succeeding shipment of paper is more and more off-color.

The wire used for "stitching" publications such as the JOURNAL is also a critical war material, and already the printers are resorting to the sewing machine in binding the JOURNAL. This really produces a better magazine, but it is a slower operation than the use of wire staples and, consequently, a more costly one.

Fortunately, we are reasonably well up to date on the publication of manuscripts as compared with most journals of scientific societies such as the American Society of Agronomy. It is reasonably certain, however, that declining revenues and even slight increases in printing costs will mean some curtailment in the volume of printing that we can do this coming year. All that we can promise is that everything possible will be done to keep manuscripts moving.

Along this line mention should be made of the splendid service rendered throughout the year by the Editorial Board and the reviewers in aiding many contributors to achieve greater condensation of their material. Contributors to the JOURNAL, too, have been most cooperative in accepting suggestions looking to conservation of space.

One development during the year that is a direct outgrowth of the war and that gives us some concern for the future is the matter of censorship. In looking back over 1942 it seems to us that the major portion of our time has been consumed in filling out questionnaires and forms for the Office of the Censor and in conducting correspondence with various officials responsible for enforcement of the censorship.

The JOURNAL is subject to licensing for export by the Publication Section of the Technical Data License Division of the Board of Economics Warfare of the Office of Censorship because it contains articles dealing with new scientific and technical processes. We are also restricted in the publication of meteorological data if the JOURNAL is to continue to be shipped out of the country. According to a communication from Colonel W. Preston Cordeman, Chief Postal Censor, "There is no objection to the export of weather data for periods prior to December 1, 1941. There is, however, objection to the export of daily, monthly or yearly summaries of meteorological data covering periods subsequent to December 1, 1941". It is in connection with such weather data that we shall have to exercise greatest care.

The procedure is this. As the galley proofs for each succeeding number of the JOURNAL are received from the printer, two sets are submitted to the Technical Data License Division, together with an application for an export license. These proofs are examined by that office and are then returned to us with authorization to export that particular number of the JOURNAL within certain limitations. Obviously, the JOURNAL cannot be sent to enemy countries, enemy occupied countries, or enemy controlled countries, and at present it cannot go to the following countries: Spain, Sweden, Switzerland, Portugal, Turkey, Argentina, and Chile.

Thus far, the JOURNAL has not been challenged at any point by the censor. If and when the problem should ever present itself of deleting an article or part of an article to meet censorship requirements in order to export the JOURNAL, we would recommend that we discontinue foreign mailings for the duration of the war; especially in view of the decreasing number of foreign subscribers. It is our understanding that mailings to Canada are not subject to the export licensing provisions of the censorship regulations.

Another interesting development of the war has been the move on the part of the American Library Association to "freeze", if you will pardon the use of a much over-worked term, a number of sets of the JOURNAL to insure a supply of back issues for foreign libraries that may wish to complete their files after the war. Several sets of the 1940 and 1941 volumes have been put on reserve for that purpose and 35 sets of the 1942 volume are being laid aside as each issue appears to meet this anticipated demand. These reservations are made on specific orders from the American Library Association which is paying for these numbers out of a fund set up for that purpose.

In conclusion, we wish to express our special thanks to the Editorial Board and the reviewers who have labored so efficiently during the year, to the office of the Secretary-Treasurer for their complete cooperation, and to the various correspondents who have supplied us with information about items of interest to the readers of the JOURNAL. If there is any improvement in these relationships that we could suggest for 1943, it would be that we be kept better informed on matters of agronomic interest, particularly with regard to agronomists who go into the armed forces. Some time in the near future we should very much like to record in the JOURNAL the names of all of our colleagues in the American Society of Agron-

omy who are now serving in the armed forces. This should be as complete a list as possible which means the fullest cooperation of all state representatives.

Respectfully submitted,

J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society during the past year may be summarized as follows:

Members, October 31, 1941			1,199
New members, 1941	110		
Reinstated members	15		
Total increase	125		
Dropped for non-payment of dues		108	
Dropped—Service suspended		7	
Resigned		42	
Mail unclaimed		11	
Died		3	
Total decrease		171	
Net decrease			46
Membership, October 31, 1942			1,153

The changes in subscriptions are as follows:

Subscriptions, October 31, 1941		668
New subscriptions, 1942	73	
Reinstated subscriptions	12	
Service suspended	5	
Subscriptions dropped	255	
Net decrease		175
Subscriptions, October 31, 1942		493

The paid up membership and subscription list by states and countries is as follows:

	Members	Subscriptions		Members	Subscriptions
Alabama	20	1	Indiana	26	4
Arizona	14	8	Iowa	37	4
Arkansas	11	7	Kansas	40	4
California	54	16	Kentucky	12	4
Colorado	20	1	Louisiana	19	7
Connecticut	13	3	Maine	6	1
Delaware	4	1	Maryland	24	5
District of Columbia	81	7	Massachusetts	11	4
Florida	24	4	Michigan	30	5
Georgia	14	5	Minnesota	28	7
Idaho	9	2	Mississippi	17	4
Illinois	60	17	Missouri	16	5

	Members	Subscriptions
Montana	7	6
Nebraska	36	4
Nevada	3	1
New Hampshire	3	1
New Jersey	19	6
New Mexico	8	2
New York	48	14
North Carolina	32	7
North Dakota	15	1
Ohio	48	8
Oklahoma	12	7
Oregon	19	5
Pennsylvania	25	10
Rhode Island	6	0
South Carolina	18	2
South Dakota	7	1
Tennessee	19	3
Texas	51	20
Utah	22	7
Vermont	5	1
Virginia	25	2
Washington	19	5
West Virginia	9	1
Wisconsin	43	4
Wyoming	7	1
Alaska	1	1
Hawaii	5	10
Philippine Islands	0	0
Puerto Rico	3	4
Africa	2	23
Argentina	7	18
Australia	0	28
Belgian Congo	0	3
Bolivia	0	1
Brazil	2	8
British Guiana	0	1
British West Indies	1	1
Canada	20	46
Ceylon	0	3
Chile	2	2
China	0	0
Colombia	2	2
Cuba	3	3
Denmark	0	0
Dutch East Indies	0	3
Egypt	0	0
England	0	14
Fed. Malay States	0	0
Fiji	0	1
Finland	0	0
Germany	0	0
Greece	0	0
Guatemala	0	2
Haiti	0	0
Honduras	0	2
India	2	15
Indochina	0	0
Ireland	0	1
Italy	0	1
Japan	0	0
Mauritius	0	1
Mesopotamia	0	1
Mexico	1	1
New Zealand	0	6
Norway	0	0
Palestine	0	0
Persia	0	0
Peru	0	4
Portugal	0	0
Scotland	3	1
Spain	0	0
Sweden	0	0
Switzerland	1	0
Thailand	0	0
Turkey	0	0
Uruguay	1	0
Russia	1	0
Venezuela	0	2
Wales	0	3
Total	1,153	457

The membership of the Society has held up very well in spite of the war. The decrease is largely the result of the loss of foreign members, but there has also been a slight reduction in membership in the United States. This is largely due to the fact that some of our active and prospective members have been called to service.

The decrease in subscriptions is due largely to the loss of foreign subscribers in Europe and Asia. It is unlikely that we will lose many more subscribers during

the next year. The American Library Association is purchasing 35 copies of the current volume for later distribution to foreign libraries and will probably continue this practice.

The efforts of various members in securing new members and in encouraging old members to retain membership is deeply appreciated. Your continued support will help greatly in maintaining our Society during this critical period.

Respectfully submitted,

G. G. POHLMAN, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year ending October 31, 1942.

American Society of Agronomy		$12,634.53
Soil Science Society of America		4,786.34
Marbut Memorial Fund		83.15
International Society of Soil Science		257.00
Endowment Fund, International Society of Soil Science		2.25
Total receipts		$17,763.27
Balance on hand, October 31, 1941		4,106.44
Total income		$21,869.71
American Society of Agronomy		$12,925.99
Soil Science Society of America		5,301.41
International Society of Soil Science		45.00
Total disbursements		$18,272.40
Less checks outstanding		21.95
		$18,250.45
Balance on hand, October 31, 1942	$3,619.26	
Balance in trust certificates	80.97	
Balance in savings bonds	2,460.00	
Total assets, October 31, 1942		$6,160.23

These assets are divided as follows:

	Cash	Trust certificates	Savings bonds	Total
American Society of Agronomy	$ 813.97	$44.92	———	$ 858.89
Soil Science Society of America	−14.60*	——	———	−14.60*
Marbut Memorial Fund	1,063.24	36.05	———	1,099.29
International Society Soil Science	1,537.48	——	———	1,537.48
Endowment fund (I.S.S.S.)	219.17	——	$2,460.00	2,679.17
Total assets	$3,619.26	$80.97	$2,460.00	$6,160.23

*Deficit.

A breakdown of receipts and expenditures for the American Society of Agronomy for the year ending October 31, 1942 is as follows:

RECEIPTS

Miscellaneous		$ 576.34
Advertising		1,519.55
Reprints sold		1,850.51
Journals sold		245.81
Subscriptions, 1941		481.33
Subscriptions, 1942 (old)		1,874.83
Subscriptions, 1942 (new)		236.50
Subscriptions, 1943 (advanced)		199.52
Dues, 1941		65.50
Dues, 1942 (old)		4,977.54
Dues, 1942 (new)		534.50
Dues, 1943 (advanced)		50.50
Index		16.90
Abstracts		5.20
Total receipts		$12,634.53
Balance on hand, October 31, 1941		1,093.48
Total income		$13,728.01

DISBURSEMENTS

Printing the JOURNAL, cuts, etc		$9,796.24
Salary of Editor		745.00
Postage, Editor and Secretary		211.84
Printing, miscellaneous		184.33
Express		2.10
Mailing clerk and stenographer		1,257.09
Refunds, checks returned, etc		63.13
Expenses for meetings		532.44
Miscellaneous		133.82
Total disbursements		$12,925.99
Less checks outstanding		11.95
		$12,914.04
Total income	$13,728.01	
Less total disbursements	12,914.04	
Balance in checking account Oct. 31, 1942	813.97	
Balance in trust certificate	44.92	
Total assets		$ 858.89

The income of the Society is somewhat less than reported last year, the greatest decrease being in subscriptions which was largely the result of the loss of many of our foreign subscribers, particularly from Japan. We have also suffered a loss in number of new members, primarily because of the fact that so many of the young

trained agronomists have been called to active service. These losses have been met, in part, by an increase in advertising income and by a decrease in expenditures. It is doubtful if much further reduction in expenditures can be accomplished without decreasing the size of the JOURNAL since costs of printing and many other items have increased during the past year and will probably continue to do so. The Society is counting on you to help maintain the financial standing of the Society by giving it your continued support.

Respectfully submitted,

G. G. POHLMAN, *Treasurer.*

AUDITING COMMITTEE

THE members of the Auditing Committee have examined the books of the Treasurer of the American Society of Agronomy and find the accounts correct as reported.

B. A. BROWN

THOMAS L. MARTIN, *Chairman*

THE AMERICAN SOCIETY OF AGRONOMY AND THE WAR

THROUGH its long-established leadership, the American Society of Agronomy has encouraged and supported activities which have led to contributions in the production of food, fiber, and industrial products of the most vital and strategic significance to the war effort. Scientific methods for soil improvement and conservation have provided a practical basis for a permanent agriculture which is the life blood of any nation. Explorations and investigations have brought new and highly useful species into widespread culture and utilization. Lespedeza, grain sorghums, soybeans, and many others have not only enhanced the supplies of the feed and food but have resulted in the establishment of many prominent industrial enterprises whose products are of great direct importance in the present emergency. Through the syntheses of germ plasm from all parts of the earth, new and superior varieties have been developed which have reduced the devastating losses from plant diseases, cold, heat, drought, and other natural hazards, enhancing and stabilizing the levels and economy of production to a remarkable degree. Hybrid corn, now constituting from 70 to 98% of the corn acreage of the leading Corn Belt states; disease-resisting oats now rapidly replacing susceptible varieties in the same region; and many other such achievements exemplify the far-reaching character of the contributions of agronomists to the national welfare in this emergency. For such accomplishments to the security of the nation the members of the Society may be justly proud.

Our country is at war. In this period many additional responsibilities are being added to a reduced personnel. It is, therefore, appropriate that at this, its annual meeting, the American Society of Agronomy consider ways and means to reorganize our efforts and redefine our policies to meet the to fullest degree, not only the immediate demands but the future needs of this country.

The trying problem before us is to satisfy the current requirements for services that are paramount to the national welfare without the abandonment or serious impairment of the continuity of those basic lines of effort in research, teaching and extension which have been so fruitful in the past. Now, more than ever before, are they indispensible to the current war effort and to the reconstruction period which is to follow.

Agronomists have responded resolutely to the war effort in the armed forces where so many brilliant and promising staff members and graduate students are given their all. Those remaining in civilian service are continuing the strong leadership and the work which in no small degree have made possible the remarkable current productions of food despite the handicaps and adversities of a wartime economy. The spirit and the letter of the Selective Service Act has made such civilian efforts and leadership possible but more caution is needed to avoid the loss of key men to the armed forces with the resultant disorganization of personnel for the advanced training of scientific talent and for the education of our rural people. A broad outlook is needed at this time if we are to cope with current needs and the new problems of a new world.

Bearing in mind these basic considerations and the extreme difficulties of their attainment and that agricultural production may be of far greater strategic value in 1943 than ever before, your committee is offering for your consideration a number of suggestions most of which relate primarily to current problems. It is the hope of your committee that they may help to define more clearly our position in the war and post-war periods.

It is recommended:

1. That occupational deferment continue to be requested for key men in research, teaching, and extension so as to preserve an adequate organization for the training of scientific personnel to serve the Nation during the war period and during the reconstruction period which is to follow.
2. That advanced consideration and study be given to the probable future needs and adjustments for the training of men for international service in agriculture and for the training of foreign students from South America and other countries.
3. That adjustments be made when possible for the temporary release on a whole or part-time basis of personnel of the staffs of departments when such personnel is necessary and peculiarly fitted for strategic posts in the national emergency either in special researches or in other fields.
4. That the agronomists in regional areas contact each other by correspondence or otherwise where common problems prevail. Particularly is this pooling of information and judgments essential when frost damage to growing crops, winter losses, disease epidemics, and other emergencies of this character prevail.
5. That in those regions where hemp production is suitable, agronomists render every possible effort to aid the government in the expansion of the hemp acreage so as to provide a satisfactory substitute for fibers of strategic significance which are no longer imported, and that assistance be provided in all efforts to adjust acreages of any crops necessary to meet the primary needs of our nation at war.
6. That cooperation in the investigations on plants which promise to become significant sources of rubber be continued and extended and that trials on new crops whose products were previously imported, such as castor beans, rape seed, and others, be established where there is promise of their adaptability.
7. That researches on turf grasses and legumes be fostered and all possible aid in the establishment of vegetative cover on airports, ordinance plants, highways and other military posts be provided.
8. That agronomists continue the researches on the fertilization of soils; to evaluate and publish the data available; and to cooperate on a regional basis

in preparing recommendations for the most judicious and effective use of fertilizers during the present emergency urging farmers to obtain their requirements at the earliest possible moment so as to prevent "bottlenecks" in distribution and that these recommendations take into consideration the severe limitations of the supply of nitrogen available for 1943.

9. That in the event of seed scarcities, special emphasis be placed upon the allocation of supplies in accordance with their adaptations, and upon judicial reductions in the rates of seeding so as to make the existing supplies go as far as possible.
10. That the controls for the protection of crops through seed treatments, dusting, and all other means of reducing the hazards of crop production be amplified as a contribution to the war effort.
11. That every effort be made to encourage the production of seeds of strategic significance to our agriculture and to that of our Allies and to build reserves of foundation stocks of superior varieties and strains, such as the foundation stocks of hybrid seed corn and the foundation stocks of other superior varieties including those not yet released but which appear promising.
12. That a study be made of the available supplies of hybrid seed corn and soybeans for seed and the effect that frost has had upon both quantity and quality of such seeds and to make recommendations accordingly.
13. That surveys be made of the existing supplies of seed of all essential crops including emergency crops and pasture supplements since they may be urgently required especially if the legume hay acreage is reduced through winterkilling and other losses.
14. That the certification of seeds of improved varieties be not relaxed or improvised but that it be adequately supported and amplified to provide full assurance of varietal identity and quality.
15. That concise pamphlets on all farming practices relating to pastures improvement and to crops that are most strategic in the war effort be prepared and that a maximum use of the radio, the agricultural press and all other agencies be made as effective means of disseminating agricultural information that will aid in a maximum production in 1943.
16. That the American Society of Agronomy, as an organization of scientifically trained men fully cognizant of their responsibilities in dealing with the problems of crop production upon which the sustenance of the nation and the world is almost wholly dependant, will continue to provide the facilities and influence of its organization in the fullest support of the war effort and in the solution of the problems of the post-war period.
17. That a committee of the Society be appointed to coordinate the war efforts of agronomists; to cooperate with committees in allied fields such as pathology and entomology; and to provide leadership in the adjustments essential to the war and post-war periods.

M. F. Miller
R. D. Lewis
L. F. Graber, *Chairman*

FERTILIZERS

FERTILIZER APPLICATION

The subcommittee on fertilizer application has continued to participate in the work of the National Joint Committee on Fertilizer Application. During the year major effort has centered on studies dealing with the plowing under of fer-

tilizer for cultivated crops. This has involved work in approximately 20 states and both field and vegetable crops. Comparisons have been made between the usual row or broadcast surface applications and applications made by applying the fertilizer on the surface and plowing under and by applying in bands on the bottom of the furrow, also various combinations of surface and plowing under. Although the effectiveness of the plow-under methods has varied with soil, crop, weather and the fertilizer used, and reasons for these variations are not yet fully understood, in general, the results for the plow-under methods are considered very encouraging and fully warranting continued and thorough investigation.

Although the restrictions imposed upon the farm equipment industry by the War Production Board are preventing the production of much new improved fertilizer equipment, one promising new "once-over" one-mule power combination planter and fertilizer distributor, adapted to cotton and other row crops, has been developed by the North Carolina Agricultural Experiment Station. It is believed that this machine may remove one of the important limiting factors to the wider adoption of better fertilizer placement on many of the smaller farms in the South.

ROBT. M. SALTER, *Chairman*

FERTILIZER GRADES

REPRESENTATIVES of the War Production Board, the Office of Price Administration, and the U. S. Dept. of Agriculture have accomplished a great reduction in the number of fertilizer grades offered for sale in all states where the number was not already greatly restricted. The committee appreciates the good work which has been done.

The committee recommends that attention be given to three problems, as follows: (1) That steps be taken so the gains made in grade reduction will not be lost when government control is removed; (2) that an effort be made to harmonize more closely the grade recommendations in adjoining states; and (3) that perhaps grade reduction has been too drastic in some cases.

C. E. MILLAR, *Chairman*

FERTILIZER REACTION

THE subcommittee has not been active during the year, and in view of the fact that the major problems in this field have been solved, it is recommended that the subcommittee be discontinued.

F. W. PARKER, *Chairman*

DIAGNOSIS OF NUTRIENT STATUS OF SOILS AND CROPS

THIS new subcommittee recognizes an opportunity to increase our services to agriculture by promoting a more extensive interpretation of the basic principles of the plant and soil sciences in practical use. Every agricultural teacher, county agent, progressive farmer, or grower of plants has need for the facts of our science. These people are the doctors who do much of the prescribing in correcting nutritional problems of the nation.

This subcommittee proposes to build a program of reporting *case histories of diagnostic procedures in the nutrition of plants*. An accumulative file or library on case histories should help to point out the need for basic information and to set forth examples on how such information can be used. In other words, we should

deplore "blanket fertilizer recommendations" and attempt to build up an understanding of how to use scientific information. A long list of case histories that one could study much as the medical men use them, should be helpful. Action along this line is already started by the subcommittee.

GEORGE D. SCARSETH, *Chairman*

SPECIAL COMMITTEE ON NITROGEN

THE Special Committee on Nitrogen recommends to the Society that its President be authorized to appoint five members to serve as a Committee on Nitrogen Utilization.

The functions of this Committee would be:

1. To aid in planning and promoting a well-balanced research program on nitrogen in relation to the use of the large supplies of this element that will probably be available to agriculture after the war is over.
2. To represent the Society on the National Joint Committee on Nitrogen Utilization.

R. W. CUMMINGS
W. H. PIERRE
S. C. VANDECAVEYE
N. J. VOLK
F. E. BEAR, *Chairman*

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

THIS committee was appointed at the request of the members present at the Seventh Eastern Wheat Conference held at Lafayette, Indiana, on June 19–20, 1941, for the purpose of attempting to develop a uniform standardized system of nomenclature and symbols for genetic factors in wheat.

The request was based on a paper presented on this subject by Dr. W. W. Worzella in which he reviewed some 200 papers involving the inheritance of more than 60 different characters in hexaploid wheats and suggested a proposed system of nomenclature. Many genetic studies have been reported in wheat, but only a few characters have been analyzed systematically. In addition, there is a haphazard allocation of gene symbols which has become inconvenient and confusing.

Your committee is considering a system of nomenclature in which the symbol consists of the initial letter of the name of the character or the initial letter of some other appropriate word in the name along with alphabetical and numerical subscripts to designate different gene symbols for a character. The system, similar to that used by the drosophila, maize and barley geneticists, is flexible and can be expanded easily.

The committee hopes to be able to present a complete summary and its recommendations by the next general meeting.

L. P. REITZ
FRED N. BRIGGS
J. B. HARRINGTON
WALLACE W. WORZELLA
E. R. AUSEMUS, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

THE following crop varieties have been submitted to the committee during the year and have been approved for registration.

BARLEY

Santiam, developed by Oregon State College.

COTTON

Bobshaw, bred by John W. Oakley, Heathman, Miss.

FLAX

Biwing and Redson, developed by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

OATS

DeSoto, developed by the Arkansas Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Bridger, developed by the Montana Agricultural Experiment Station and the U. S. Dept. of Agriculture.

RED CLOVER

Cumberland, developed by the U. S. Dept. of Agriculture in cooperation with the Kentucky, Virginia, and Tennessee agricultural experiment stations.

Midland, developed by the U. S. Dept. of Agriculture in cooperation with the Ohio, Illinois, Indiana, and Iowa agricultural experiment stations.

SWEETCLOVER

Spanish, developed by the U. S. Dept. of Agriculture in cooperation with the Nebraska, Kansas, and Washington agricultural experiment stations.

Madrid, developed by the U. S. Dept. of Agriculture in cooperation with the Kansas, Nebraska, Oklahoma, and Washington agricultural experiment stations.

Evergreen, developed by the Ohio Agricultural Experiment Station.

SOYBEAN

Boone, developed by the Missouri Agricultural Experiment Station.

WHEAT

Pawnee, developed by the Nebraska and Kansas Agricultural Experiment Stations and the U. S. Dept. of Agriculture.

Comanche, developed by the Kansas Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Descriptions of these new varieties will be published in the JOURNAL.

Interest in the registration of improved varieties of additional crops is increasing. From time to time the committee is requested to provide for the registration of crops not now authorized. The committee therefore asks the Crops Section of the American Society of Agronomy either to authorize the committee itself to make determinations relative to the registering of additional crops or to authorize the Executive Committee of the Society to approve such authorization upon presentation of recommendations with evidence by the committee.

A. C. ARNY	L. F. GRABER	W. J. MORSE
H. B. BROWN	H. K. HAYES	T. R. STANTON
J. A. CLARK	E. A. HOLLOWELL	T. M. STEVENSON
E. F. GAINES	R. E. KARPER	G. H. STRINGFIELD
		M. A. MCCALL, *Chairman*

STUDENT SECTIONS

BECAUSE of wartime conditions the activities of student agronomists have been reduced. However, 23 institutions maintain active chapters and the American Society of Agronomy has issued approximately 500 certificates of membership.

The national essay contest made possible by a grant from the Chicago Board of Trade was conducted as usual. The subject for the 1941–42 contest was "Plants as Indicators of Soil Deficiencies and Crop Adaptation". This year a $50 war bond will go to each of the three highest ranking contestants. The winners of the fourth, fifth, sixth, and seventh places will receive war savings stamps in the amounts of $20, $15, $10, and $5, respectively. The three highest men will be given the customary medals indicative of their achievements.

The 10 ranking contestants and their institutions follow:

1. John G. Moseman, Jr., University of Nebraska.
2. Philip A. Miller, University of Nebraska.
3. Lester I. Culp, University of Illinois.
4. Dwight Kerley, University of Illinois.
5. Leland F. Grove, Iowa State College.
6. James Cress, University of Illinois.
7. Orville Indra, University of Nebraska.
8. Warren Sahs, University of Nebraska.
9. Raymond Lund, Iowa State College.
10. Wm. E. Kennedy, University of Illinois.

Abstracts of the three ranking papers are attached to this report.

The committee recommends that it be given permission to confer with the officials of the Chicago Board of Trade in determining whether the essay contest should be continued next year. The committee believes that it will be necessary to determine the effect of the war on second semester enrollment before it can be sure that the contest should be held.

ROBERT L. CUSHING	M. B. STURGIS
GEORGE H. DUNGAN	J. W. ZAHNLEY
J. B. PETERSON	H. K. WILSON, *Chairman*

LEGUME AND CEREAL CROPS AS INDICATORS OF BORON, SULFUR, AND MANGANESE

IT IS well established that boron, sulfur, and manganese are essential to proper plant nutrition. However, the exact effect of these elements on plant growth has been difficult to determine because only minute amounts are required, and excessive quantities results in physiological malformations similar to those caused by deficiencies. It is only since the beginning of the twentieth century that experimental techniques have been available which make these accurate studies possible.

The general effects on plants caused by a lack of boron are a yellowing of the tips and margins of the leaves, retarded growth, production of sterile seed, decreased protein content of the plant, and premature defoliation followed by death.

Through the use of such recently improved experimental techniques, as pure nutrient solutions, definite physiological effects of boron deficiency have been found. The lack of boron has been found to cause disintegration of parenchyma cells which prevents differentiation of the leaf cells, the phloem and zylem tissues degenerate, and the leaves die. Because of the abnormal meristematic activity

in the root tips caused by this deficiency the root nodules of legumes are decreased in size and number.

The malformation caused by excessive amounts of boron are a reddening and curling of the margins of the new apical or the lower leaves, spindly growth, poor root development, and if the concentration is large enough it kills the plants. In barley, striped lesions often confused with barley stripe disease are produced.

Studies of sulfur requirements have been complicated by the difference in the degree of retention by soil of the sulfur in various compounds. The main function of sulfur in the soil is to convert insoluble basic compounds into soluble forms.

No evidence has been found indicating that sulfur is essential for the growth and reproduction of cereal crops. However, leguminous plants grown in soils lacking in sulfur show lack of vigor, have lighter colored chlorophyll, and lose their lower leaves. The root nodules of these plants are small, slender, and branch very little. The resultant poor assimilation of the nitrates accumulated in the soil, causes the plants to contain less nitrogen.

Excessive amounts of sulfur lowers the pH of the soil. This often interferes with plant metabolism, and if extreme, may cause death.

Manganese is found to aid in nitrogen assimilation, protein synthesis, photosynthesis, and the chlorophyll formation. The physiological effects of plants grown in manganese deficient soil are chlorosis of the upper leaves, loss of vigor, depression of growth, disintegration of the parenchyma tissue in the basal portion of the leaf, and underdevelopment of the reproductive organs. In corn the lack of manganese causes a chlorotic condition often confused with bacterial leaf spot. Marsh spot of pea, a cotyledonal disease rendering the product unsalable, is caused by the lack of manganese.

The browning of roots and the bleaching of leaves are the most evident effects of excess amounts of manganese in the soil.

Study of these and other symptoms of deficiency or excess of boron, sulfur and manganese will be of increasing economic value as a basis for judicious selection of crops in those areas in which growth of crops is limited by a deficiency or excess of one or more of these elements.—JOHN GUST MOSEMAN, JR., *University of Nebraska.*

THE USE OF *Aspergillus niger* AND *Azotobacter* TO DETERMINE SOIL DEFICIENCIES

ASPERGILLUS niger and *Azotobacter* are simple plants which are well suited for use in testing for soil deficiencies by reason of their rapid growth and response to the presence or absence of soil nutrients. Biological tests using these microorganisms are rapid, inexpensive, simple in procedure, and require only a small amount of space.

As early as 1909 it was first suggested that *A. niger* be used as a biological indicator of the available phosphorus and potassium in soils. Since then a detailed procedure for such a test has been developed. A small portion of soil is mixed with a nutrient solution and inoculated with a suspension of spores of *A. niger*, and then incubated for about four days. The element to be tested for is not added to the nutrient solution, but is supplied to the mold by the soil. The mycelial growth from the *A. niger* is washed, dried, and weighed. The amount by which the weight of mycelium thus produced exceeds the amount formed in the check solution in which the element is absent, is an index of the readiness with which the mold obtains the food element, and therefore its availability in the soil tested. Different

methods are used by which the results of such a test can be used directly to make recommendations for the use of fertilizers on the soil tested.

Certain variable factors including strain of organism, age of spores used in inoculation, $CaCO_3$ content of the soil, length and temperature of incubation period, and the physical and chemical properties of the soil, greatly effect the results of this test. It is necessary to standardize these factors as much as possible to obtain the best results.

It has been generally concluded that the *A. niger* test is reliable in testing for phosphorus and potassium deficiencies. It is a rapid and simple procedure, and its results compare favorably with chemical tests, Neubauer's rye seedling tests, and actual field tests.

The *Azotobacter* soil plaque test utilizes the spontaneous development of *Azotobacter* colonies as a plant food indicator to determine deficiencies in phosphorus, potassium, and lime. Five plaques are prepared from the soil being tested. The first of these is reserved without further treatment for a check, the second receives K_2SO_4, the third Na_2HPO_4, the fourth K_2HPO_4, and the fifth $CaCO_3$. Water is added to the plaques and they are incubated for about 72 hours. At the end of this period *Azotobacter* colonies visible to the naked eye will have appeared on the plaques where the deficiency has been satisfied or where none existed, while no growth will be present where the proper limiting factor has not been supplied. The results can be used to make recommendations for use of fertilizers on the soils tested.

The same variable factors which effect the *A. niger* test also effect the results of the *Azotobacter* test. Here again there is a need for a standardization of these factors to insure reliable results.

The *Azotobacter* test is used for phosphorus, potassium, and lime deficiencies, but its accurateness is questionable, proving reliable on certain soils, but quite unreliable on others.—PHILIP A. MILLER, *University of Nebraska.*

PLANTS AS INDICATORS OF SOIL DEFICIENCIES AND CROP ADAPTATION

PLANTS are living organisms and they, like all other living things, are affected by their environment. Not all plants have the same requirements, some being better adapted to one condition than another. If we are able to determine this relationship between the plant and its environment we can tell what soil conditions exist merely by the type of vegetation present.

Native vegetation in virgin territory serves as a good indicator of soil deficiencies and crop adaptation. In prairie regions, a short-grass cover indicates productive soil with only a small amount of moisture. Early maturing, shallow rooted crops are best adapted to this land. Bunch-grass land is adapted to deep-rooted long-season crops and is seldom affected by periods of drought as contrasted to the short-grass land. In more arid regions, a good stand and growth of sagebrush indicates land that is well adapted to both dry and irrigation farming.

Weeds serve as good soil indicators both on cultivated and unbroken land. Swamp smartweed is an indicator of poorly drained soil. Annual smartweed, horseweed, and ragweed are found on productive soils while Spanish needle and pennyroil indicate a poor soil. Sheep sorrel is found on acid soil and buckhorn indicates phosphorus deficiency.

Native forests of elm, black walnut, burr oak, linden, tulip, and sycamore in the northern states are found on good soils, beech trees on less productive soil and sassafras and scrub oak on poor soils. In a general way pine forests indicate poor soils and hard wood forests are found on good soils.

Where man has destroyed the native vegetation, we must study the responses of cultivated crops. Crops grown on land which does not meet the nutrient requirement of the plant develop certain nutrient deficiency symptoms of discoloration and abnormal growth and development. Tobacco, because of its large leaf area, is an excellent plant to use as an indicator. Through the use of controlled experiments, deficiency symptoms have been determined for many of the cultivated crops, of which corn is of major importance in the middle west.

A knowledge of indicator plants and plant nutrient deficiency symptons is useful to the farmer, agronomist, land appraiser, and others who have a major interest in agricultural production.—LESTER I. CULP, *University of Illinois.*

RECOMMENDATIONS FOR FUTURE MEETING PLACES

IN CASE the members of the Society decide to continue holding the annual meetings during the war, the following schedule for the next three years is suggested:

Year	Place	Approximate Date
1943	Cincinnati, Ohio	Second week in November
1944	Chicago, Ill.	At time of International Grain and Hay Show
1945	Denver, Colo., or in the event the U. S. is still at war, Louisville, Ky.	First week in September in case the meeting is held in Denver

In considering satisfactory meeting places, your committee has been guided primarily by the geographical distribution of the membership and by the present state of the nation. Approximately two-thirds of the membership of the Society is in the Midwest and East, one-sixth in the South, and one-sixth in the West. As long as the war continues it will be desirable to curtail travel. Cincinnati, Ohio, is strategically located with respect to the East, Midwest, and South. Chicago is suggested for the meeting place in 1944 because of its location and accessibility by rail and because of the annual meetings held in connection with the International Grain and Hay Show, some of which are of interest to agronomists. On the assumption that the war will end before 1945 and considering the fact that the last annual meeting of the Society outside the Midwest-East region was held in 1939 at New Orleans, it is suggested that the meeting in 1945 be held in the West at Denver, Colorado.

It will be noted that early September is suggested for the meeting date in Denver. If this suggestion is accepted, members of the Society will have an opportunity to inspect growing crops in that region and to extend their trip farther into the West under favorable weather conditions.

W. A. ALBRECHT — G. H. STRINGFIELD
L. D. BAVER — R. J. GARBER, *Chairman*
D. W. ROBERTSON

EXTENSION PARTICIPATION

THE primary duty of the extension agronomist is to put soil science to work on the farm and he is a busy man at the present time. The results of research must be broken up into manageable units before the farmers can use them and in the present emergency both extension agronomists and research men can help. A

thorough search should be made of the unpublished results of past research since facts that will help solve present problems may be found.

E. L. WORTHEN — O. S. FISHER
IDE P. TROTTER — EARL JONES, *Chairman*
R. D. MERCER

RESOLUTIONS

THE Committee on Resolutions regrets to announce the passing of three agronomists during the year each of whom had achieved a large measure of success in their respective fields of activity. They are Earl T. Duke, Assistant Professor of Agronomy in the Department of Plant Industry of the Texas Technological College at Lubbock, Texas; William Harold Metzger, Associate Professor of Soils, Department of Agronomy, Kansas State College, Manhattan, Kan.; and John Washington Gilmore, Professor of Agronomy, University of California, Davis, Calif.

On behalf of the American Society of Agronomy the committee makes this announcement with sorrow and a feeling of real loss to the Society and to their respective families. Expressions of regret concerning each of these men are attached to this report.

O. S. AAMODT — J. D. LUCKETT, *ex-officio*
R. W. CUMMINGS — IDE P. TROTTER, *Chairman*
R. I. THROCKMORTON

EARL T. DUKE

WHEREAS, on May 12th, 1942, the angel of death reached into the membership of the American Society of Agronomy and took therefrom one of our younger and very promising members and

WHEREAS, the death of Earl T. Duke, Assistant Professor of Agronomy, in the Department of Plant Industry of the Texas Technological College of Lubbock, Texas, removed from our midst a faithful coworker and a strong supporter of agronomic work in the country, and particularly the southwest, therefore

BE IT RESOLVED, that the American Society of Agronomy in Annual Convention assembled do express officially sorrow over its loss of so fine a character at such an untimely and early age.

Mr. Duke was a graduate of the Agricultural and Mechanical College of Texas in the class of June, 1937, having done his major work in the Department of Agronomy. During his student days he was most active in scholastic and student affairs and showed especial interest in cotton. In the spring of 1937 he was elected "King Cotton" of the Sixth Annual Cotton Style Show, Pageant, and Ball.

Following his graduation he went into the Agricultural Extension Service where his work was most successful. He was then called to Texas Technological College and advanced rapidly to the position he held at his death. His duties at that college were particularly concerned with the coaching and sponsoring of their Crops Judging Team and the teaching of their work in cotton.

WILLIAM HAROLD METZGER

WHEREAS, one of the long time and very faithful members of the American Society of Agronomy, Dr. W. H. Metzger of the Department of Agronomy, Kansas State College, Manhattan, Kansas, was taken from us by the hands of death on July 7th, 1942, at Columbia City, Indiana, following a long illness, and

WHEREAS, Dr. Metzger's departure from this life in the prime of his professional and personal career brings sorrow to us and is a distinct loss to agriculture, therefore

BE IT RESOLVED, by the American Society of Agronomy that we officially express our deep regret over the loss of so splendid an agronomist and so faithful a member of our organization.

Doctor Metzger was born September 19, 1899, in Fulton County in northern Indiana and was educated in the grade schools of the community. In 1917 he graduated from Kewanna High School. After a year's delay, he entered Purdue University, graduating with the degree Bachelor of Science in Agriculture in 1922. The following year he was Assistant in Soils at Pennsylvania State College. He then entered County Agent work in Kansas and remained in this work for somewhat more than three years. At that time he accepted an assistantship at the Kansas State College and completed requirements for a Master of Science degree in June, 1927. He then went to the University of Arkansas where for slightly more than two years he engaged in teaching and research in soils. Next he accepted a research fellowship from the Ohio Agricultural Experiment Station and obtained a Doctor of Philosophy degree at Ohio State University in 1931. In April, 1932, he began work as a teacher and research worker in soils at Kansas State College and continued in that work until illness forced him to retire.

Doctor Metzger has contributed numerous writings which have appeared in the form of articles in technical journals, experiment station bulletins, and farm papers of Kansas.

He has been a member of the American Society of Agronomy, Soil Science Society of America, American Chemical Society, Sigma Xi, Alpha Zeta, Tau Kappa Alpha, and the Kansas Academy of Science. He has held offices and committee appointments in the Soils Section of the American Society of Agronomy.

JOHN WASHINGTON GILMORE

JOHN Washington Gilmore, Professor of Agronomy and Agronomist in the Experiment Station of the University of California, died in Woodland, California, June 12, 1942. Professor Gilmore had but recently passed his 70th birthday and was scheduled for retirement from active duty at the end of the fiscal year. He is survived by his wife, Rose Marks Gilmore, and by three sons John, Raymond, and Harold.

Born in White County, Arkansas, in 1872, he received his agronomic education at Cornell University, being awarded the B.S.A. degree in 1898 and the M.S.A. degree in 1906. After graduation he went to China as Assistant Superintendent of the Agricultural School of Wuchang from 1898 to 1900. During the next two years, 1900 to 1902, he served as fiber expert for the Bureau of Agriculture of the Philippine Islands. In 1902 he returned to this country and was Assistant Professor of Agronomy at Cornell University from 1902 to 1907 and Professor of Agronomy at Pennsylvania State College in 1907 and 1908. In 1908 he went to the University of Hawaii as the first president of that institution, in which capacity he served until 1913. In the latter year he came to the College of Agriculture of the University of California as Professor of Agronomy and Agronomist in the Experiment Station and Head of the Division of Agronomy. He relinquished his administrative duties in 1923 but remained as an active member of the Division until the end.

From his early experiences Professor Gilmore developed a deep interest in the agriculture and peoples of foreign lands, and especially of the Latin American

Countries. Because of the knowledge thus developed he was frequently called upon for advice on agricultural matters by our neighbors to the south. In 1921 he spent a year in Chile as Agricultural Advisor to the Chilean government and returned again to Chile on the same mission in 1936, at which time he was awarded an honorary professorship in the University of Chile. He was called to the Dominican Republic in 1925 and to Mexico in 1930–31 on a similar mission.

Because of his extensive foreign contracts and experiences, Professor Gilmore took a personal interest in the foreign students, helping them to become acquainted and adjusted to American ways and customs. He was instrumental in the establishment of the Forum Club, designed to promote closer and more friendly relationship between foreign and American students and a better understanding and appreciation of their respective viewpoints and problems.

Professor Gilmore loved people and, in return, was beloved by all who had the good fortune to know him intimately. He was an inspiring teacher, convinced that in the education of young people would be found the substantial basis for a lasting world peace and security. He took an active interest in student affairs and was never happier than when advising and counseling with students on academic and personal problems. He will be affectionately remembered by a host of former students whose path was made easier by his kindly, fatherly guidance.

His special field of interest was fiber and oil crops.

He was a member of the American Association for the Advancement of Sciences, the American Society of Agronomy, Ecological Society of America, Alpha Zeta, and Sigma Xi.

AGRONOMIC AFFAIRS

OFFICERS OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1943

President, F. D. KEIM, University of Nebraska, Lincoln, Nebr.

Vice President, F. W. PARKER, U. S. Dept. of Agriculture, Research Center, Beltsville, Md.

Chairman of Crops Section, L. F. GRABER, University of Wisconsin, Madison, Wis.

Chairman of Soils Section, F. E. BEAR, Rutgers University, New Brunswick, N. J.

Secretary-Treasurer, G. G. POHLMAN, University of West Virginia, Morgantown, W. Va.

Editor, J. D. LUCKETT, New York State Experiment Station, Geneva, N. Y.

Members of the Executive Committee, RICHARD BRADFIELD, Cornell University, Ithaca, N. Y.; and L. E. KIRK, University of Saskatchewan, Saskatoon, Canada.

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1943

President, FIRMAN E. BEAR, Rutgers University, New Brunswick, N. J.

Vice President, L. D. BAVER, North Carolina State College, Raleigh, N. C.

Past President, HORACE J. HARPER, Oklahoma A. & M. College, Stillwater, Okla.

Secretary-Treasurer, G. G. POHLMAN, University of West Virginia, Morgantown, W. Va.

Editor, J. D. LUCKETT, New York State Experiment Station, Geneva, N. Y.

SECTION I—SOIL PHYSICS

Chairman, G. W. CONREY, Ohio State University, Columbus, Ohio.
Past Chairman, J. C. RUSSELL, University of Nebraska, Lincoln, Nebr.

Secretary, G. M. BROWNING, Iowa State College, Ames, Iowa.

SECTION II—SOIL CHEMISTRY

Chairman, HANS JENNY, University of California, Berkeley, Calif.
Past Chairman, H. D. CHAPMAN, Citrus Experiment Station, Riverside, Calif.

Secretary, C. O. ROST, University of Minnesota, St. Paul, Minn.

SECTION III—SOIL MICROBIOLOGY

Chairman, HERBERT W. REUSZER, Alabama Polytechnic Institute, Auburn, Ala.

Past Chairman, A. G. NORMAN, Iowa State College, Ames, Iowa.
Secretary, S. C. VANDECAVEYE, Washington State College, Pullman, Wash.

SECTION IV—SOIL FERTILITY

Chairman, B. A. BROWN, University of Connecticut, Storrs, Conn.
Past Chairman, R. L. COOK, Michigan State College, East Lansing, Mich.

Secretary, R. E. YODER, Ohio Agr. Exp. Station, Wooster, Ohio.

SECTION V—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

Chairman, R. E. STORIE, University of California, Berkeley, Calif.
Past Chairman, J. W. MOON, Tennessee Valley Authority, Knoxville, Tenn.

Secretary, JAMES THORPE, University of Nebraska, Lincoln, Nebr.

SECTION VI—SOIL TECHNOLOGY

Chairman, J. S. OWEN, University of Connecticut, Storrs, Conn.
Past Chairman, H. C. KNOBLAUCH, U. S. Dept. of Agriculture, Washington, D. C.
Secretary, HANS F. WINTERKORN, University of Missouri, Columbia, Mo.

MINUTES OF THE CROPS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

THE business meeting of the Crops Section of the Society was held on Wednesday afternoon, November 11, in St. Louis, Mo., before the general session of the Section.

The report of the committee on Varietal Standardization and Registration was presented by M. A. McCall (pages 1154 to 1155). The committee asked the Society for authority to approve and register varieties of crops over which it does not now have jurisdiction. Specific

mention was made of the new varieties of grasses. A motion giving the committee the authority requested was duly recorded and passed.

The committee on Nomenclature of Genetic Factors in Wheat reported progress (page 1154) and that a complete report will be made at the next meeting of the Society. A motion by W. W. Worzella that this report be accepted and the committee continued for another year was passed.

The committee on Methods of Seed Production and Utilization of Improved Strains of Forage Crops made no report.

A communication from the Soil Science Society of America was presented, requesting the appointment of a committee on Crops Terminology. C. J. Willard moved that the Crops Section of the American Society of Agronomy appoint such a committee. Motion passed.

It was announced that at future meetings only projectors for 2×2-inch slides will be supplied by the Society. If a person wishes to use standard size slides in presenting a paper he must supply his own projector.

The Nominating Committee, consisting of C. J. Willard, Ide P. Trotter, and M. T. Jenkins, nominated L. F. Garber as Chairman of the Crops Section for 1943 and H. M. Tysdal and J. A. Rigney as members of the Program Committee. They were unanimously elected.—R. L. CUSHING, *Secretary*.

NEWS ITEMS

PROFESSOR MARTIN LUTHER FISHER, Dean Emeritus of Men at Purdue University, Lafayette, Ind., died on November 24. Professor Fisher was for many years identified with the Agronomy Department at Purdue and was one of the early members of the American Society of Agronomy. After serving for several years as chief of the Agronomy staff, he was named Dean of Men from which position he retired on June 30, 1942.

—A—

ROBERT L. PENDLETON has been named Principal Soil Technologist, Division of Latin American Agriculture, Office of Foreign Agricultural Relations, U. S. Dept. of Agriculture. Dr. Pendleton was agricultural adviser and soil scientist to the Thai (Siamese) Government from 1935 to January 1941, when he was dismissed as an enemy alien and interned in the Bangkok internment camp, later returning to the United States on the diplomatic exchange ship GRIPSHOLM.

INDEX